CFHTLS Calibration(s)

N. Regnault

(LPNHE, Paris)

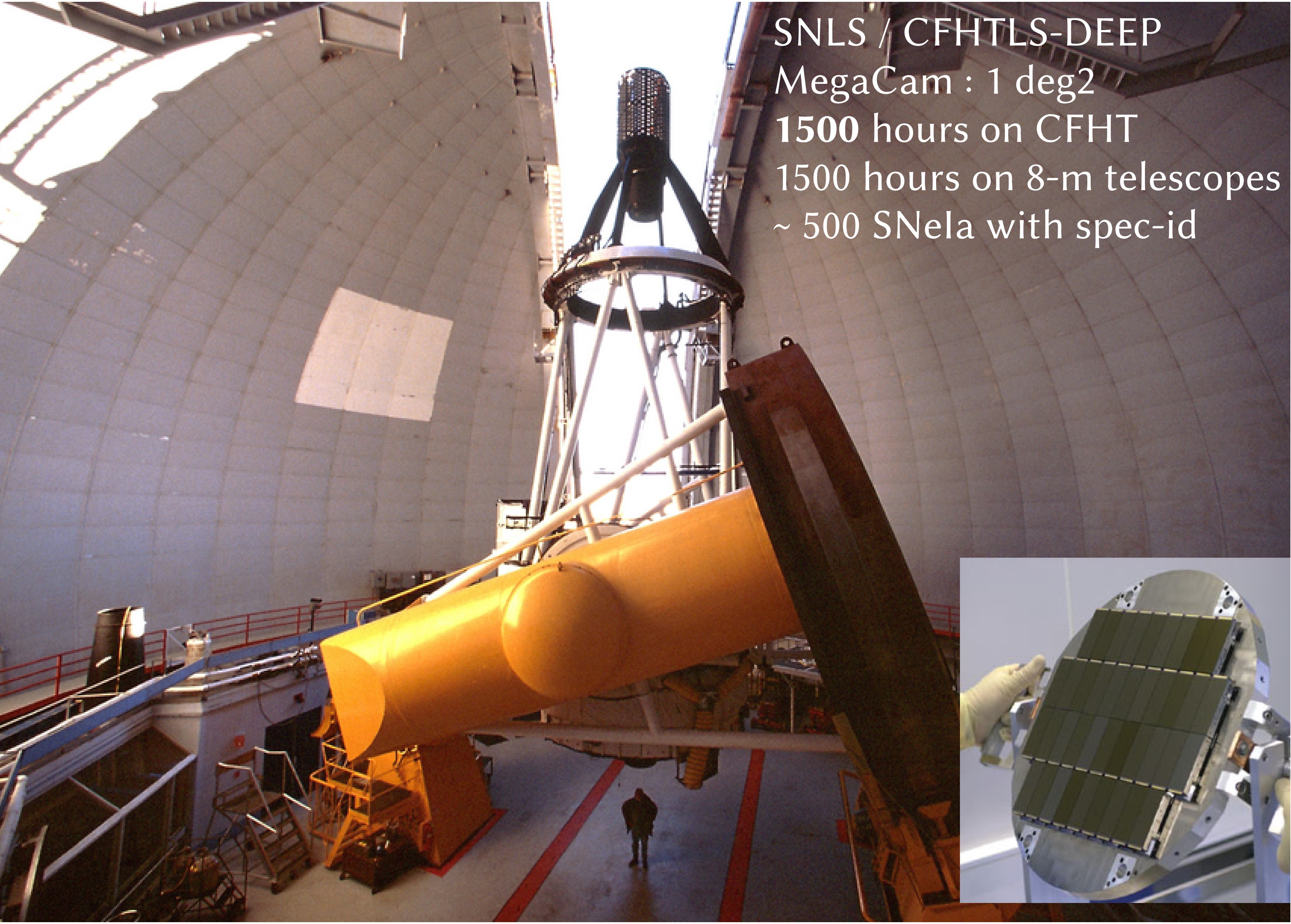
SNLS / CFHTLS-DEEP

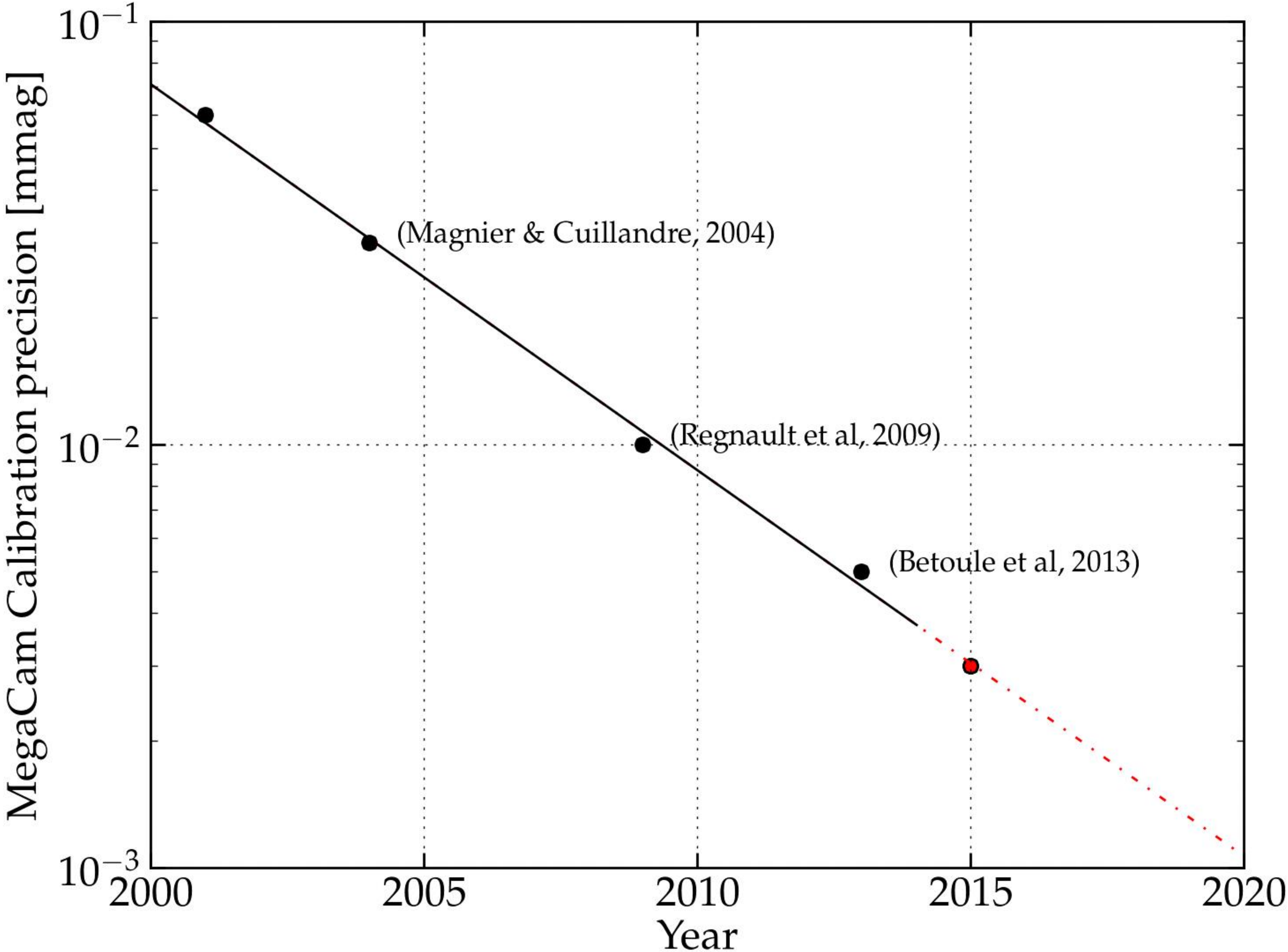
MegaCam : 1 deg2

1500 hours on CFHT

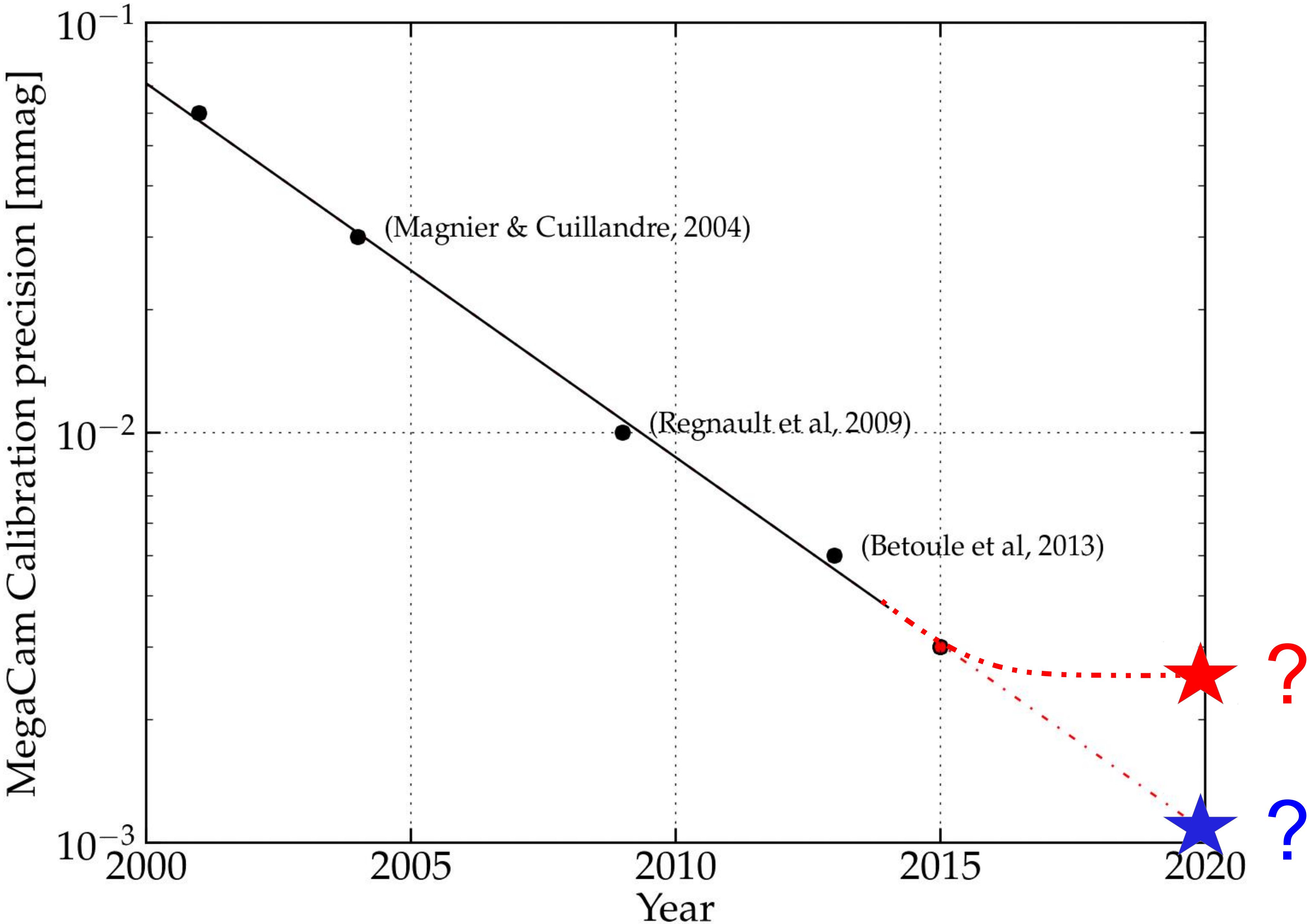
1500 hours on 8-m telescopes

~ 500 SNeIa with spec-id





10^{-1}
10^{-2}
10^{-3}
MegaCam Calibration precision [mmag]
(Magnier & Cuillandre, 2004)
(Regnault et al, 2009)
(Betoule et al, 2013)
2000
2005
2010
2015
2020
Year



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(Betoule et al, 2013)
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?
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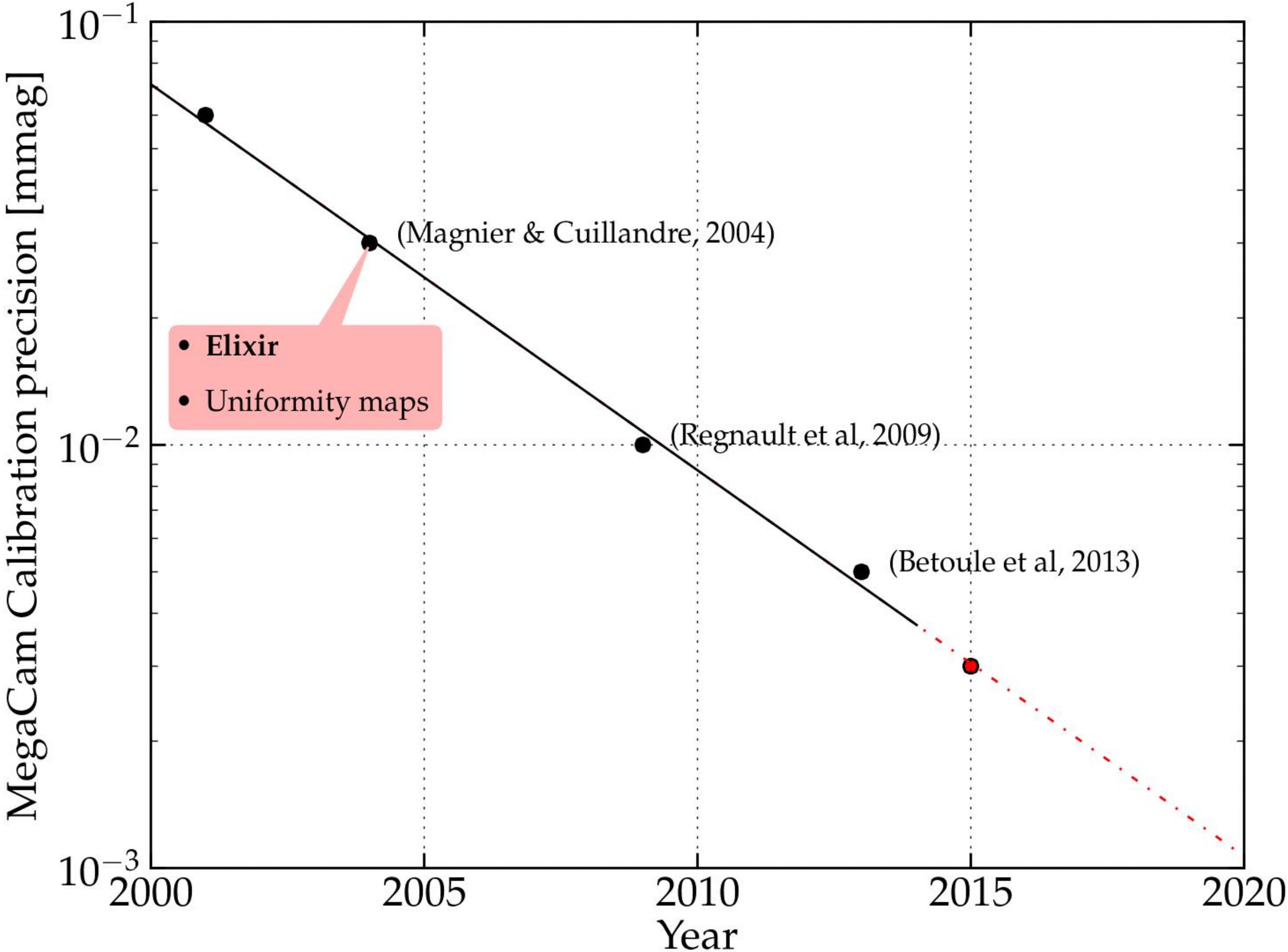

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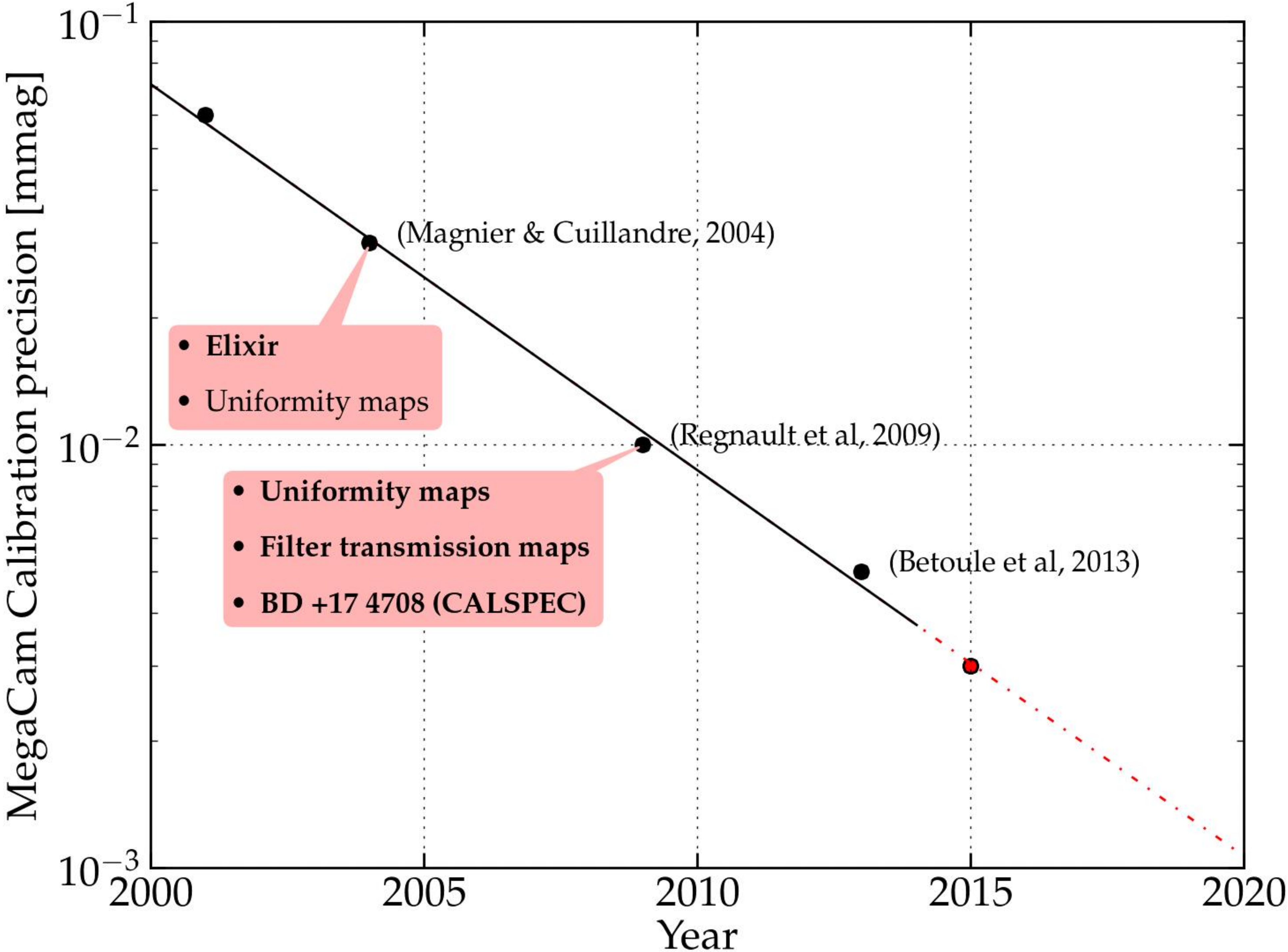
Elixir
Uniformity maps



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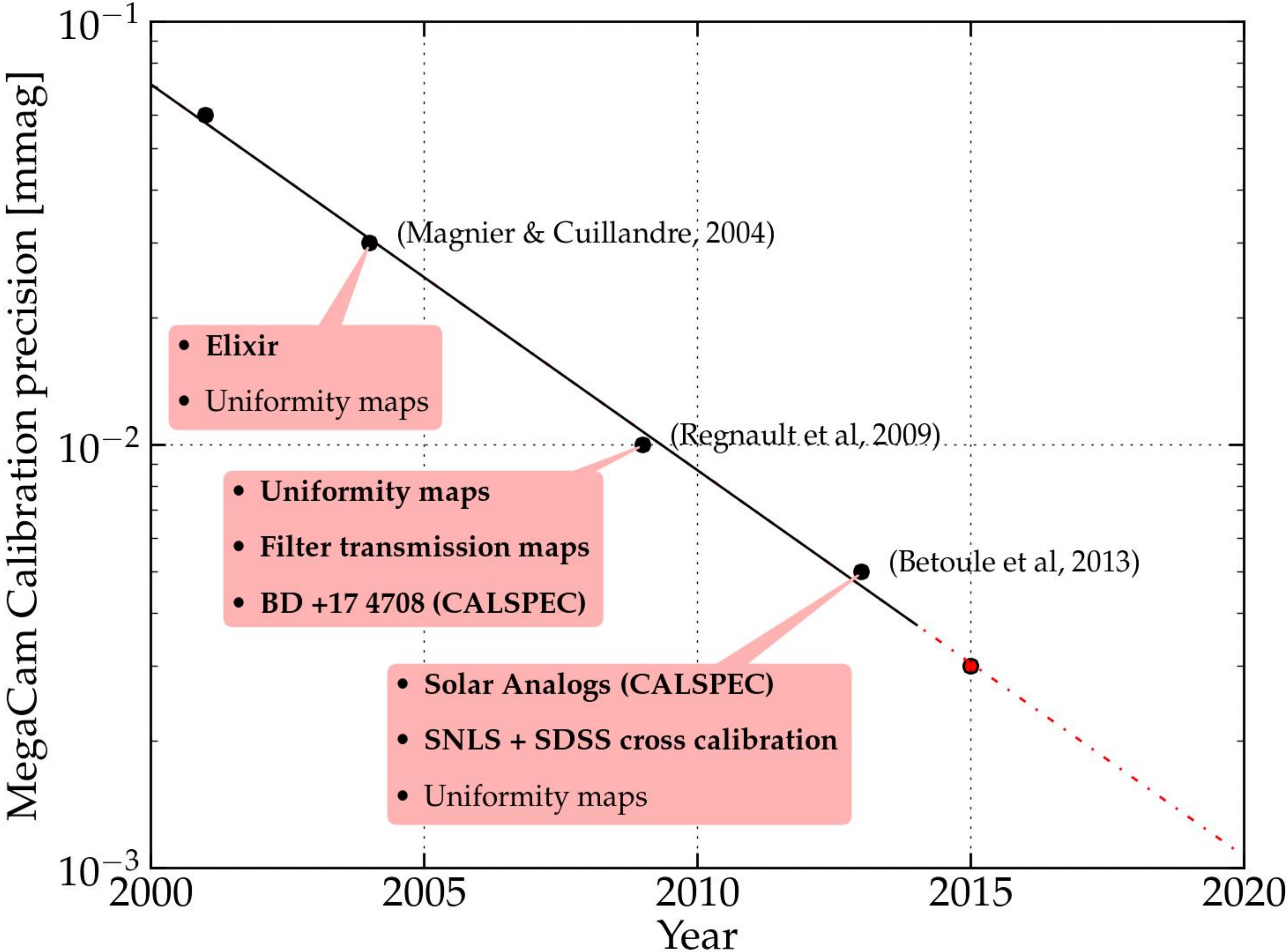
• Elixir
• Uniformity maps
• Uniformity maps
• Filter transmission maps
• BD +17 4708 (CALSPEC)



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2000
2005
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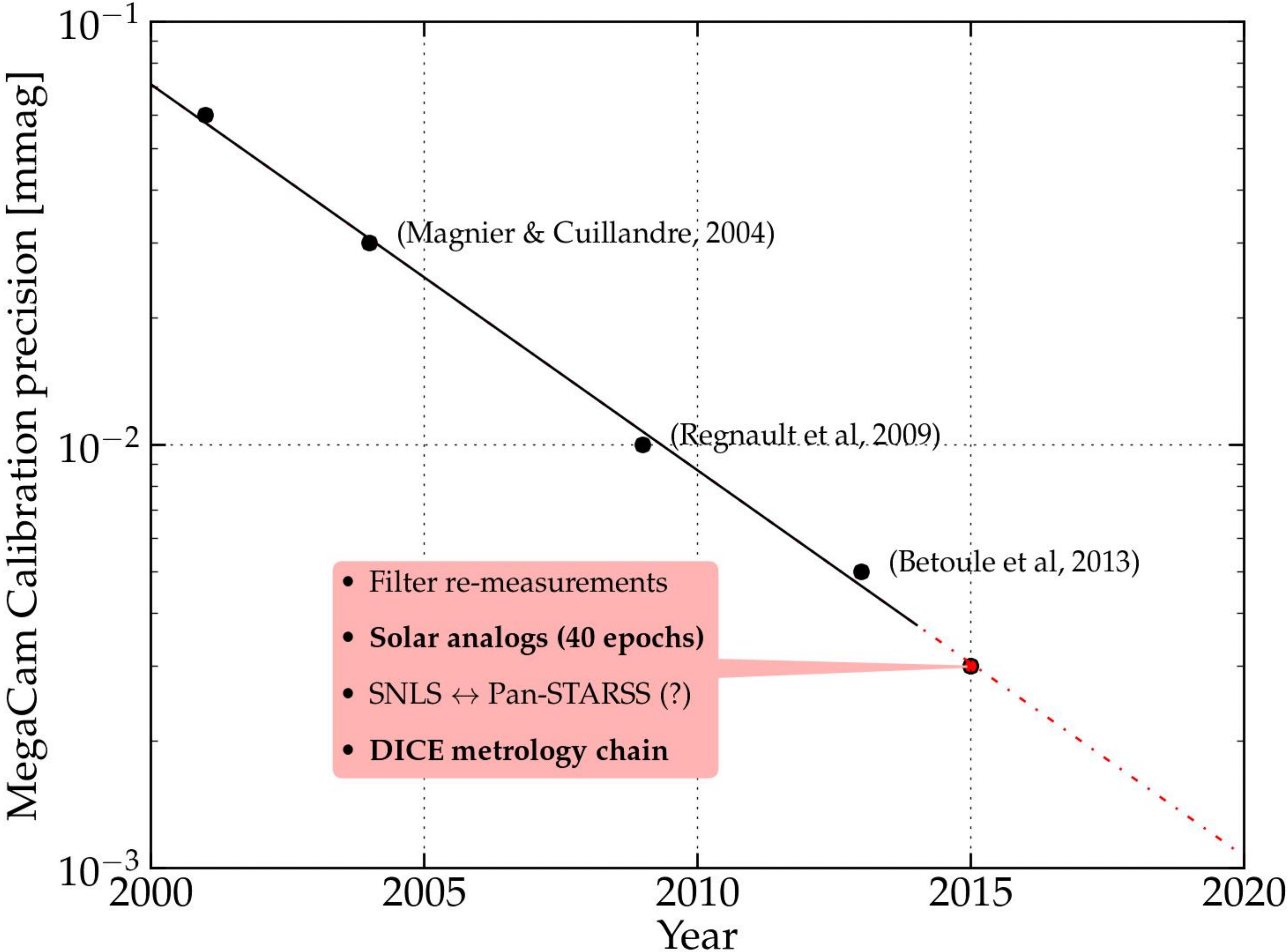
Year
(Magnier & Cuillandre, 2004)
(Regnault et al, 2009)
(Betoule et al, 2013)
• Elixir
• Uniformity maps
• Uniformity maps
• Filter transmission maps
• BD +17 4708 (CALSPEC)
• Solar Analogs (CALSPEC)
• SNLS + SDSS cross calibration
• Uniformity maps



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10^{-2}
10^{-3}
2000
2005
2010
2015
2020
Year
(Magnier & Cuillandre, 2004)
(Regnault et al, 2009)
(Betoule et al, 2013)
• Filter re-measurements
• **Solar analogs (40 epochs)**
• SNLS ↔ Pan-STARSS (?)
• **DICE metrology chain**

Why bother ?

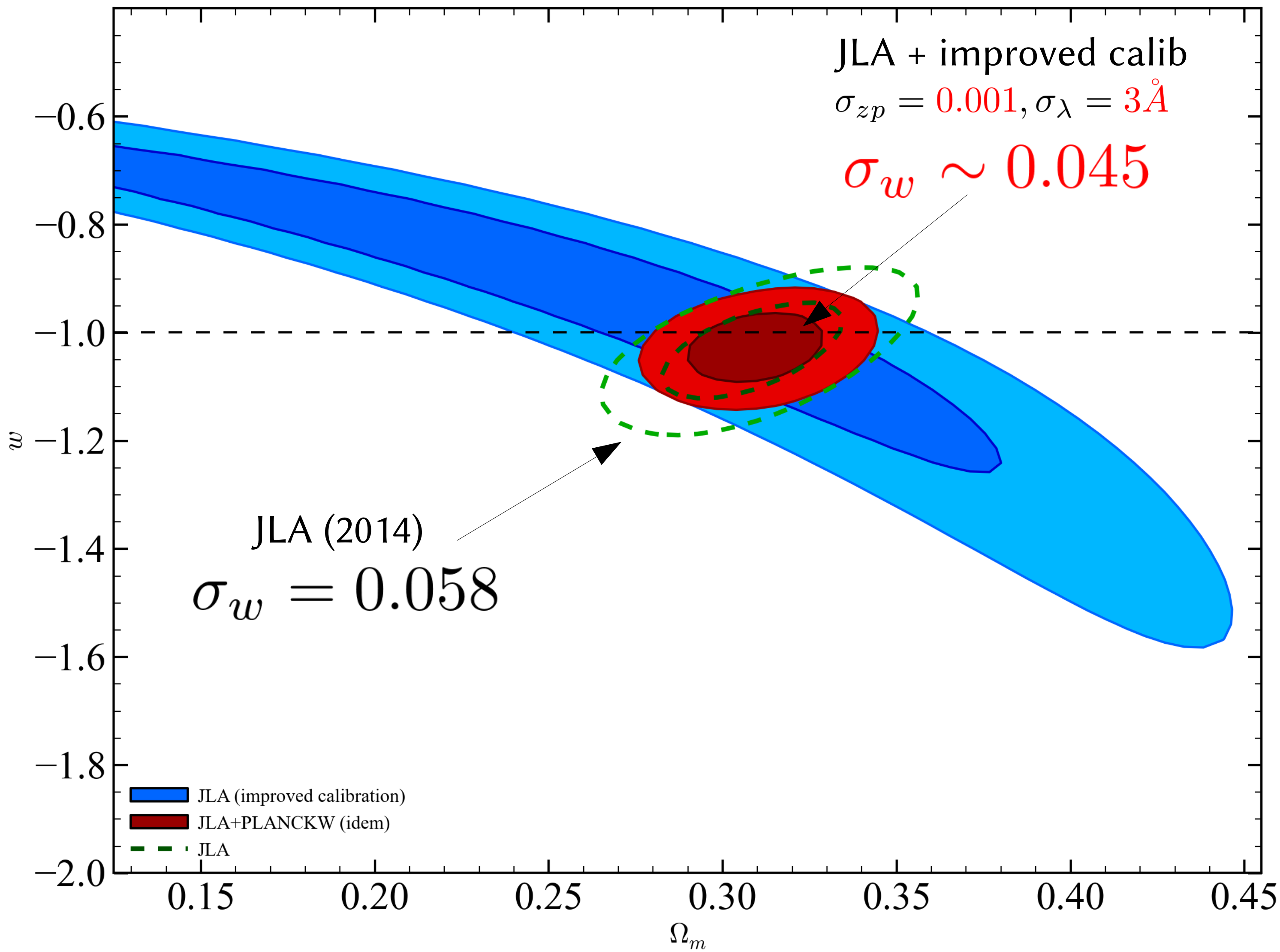
Uncertainty sources	$\sigma_x(\Omega_m)$	% of $\sigma^2(\Omega_m)$
Calibration	0.0203	36.7
Milky Way extinction	0.0072	4.6
Light-curve model	0.0069	4.3
Bias corrections	0.0040	1.4
Host relation[a]	0.0038	1.3
Contamination	0.0008	0.1
Peculiar velocity	0.0007	0.0
Stat	0.0241	51.6

(Betoule et al, 2014)

Photometric calibration dominates (by far)

the systematic uncertainty budget on w measured with SNe Ia

Why bother ?



JLA + improved calib
$\sigma_{zp} = 0.001, \sigma_\lambda = 3\mathring{A}$
$\sigma_w \sim 0.045$
JLA (2014)
$\sigma_w = 0.058$
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
−2.0
w
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Ω_m
JLA (improved calibration)
JLA+PLANCKW (idem)
JLA

Outline

- Imager Uniformity
  - Response maps / “grids” / star flats
- Precision PSF photometry
  - PSF chromaticity
  - Brighter-fatter
- Flux metrology chain
  - Fundamental flux standards
  - Building robust metrology chains
- Instrumental calibration

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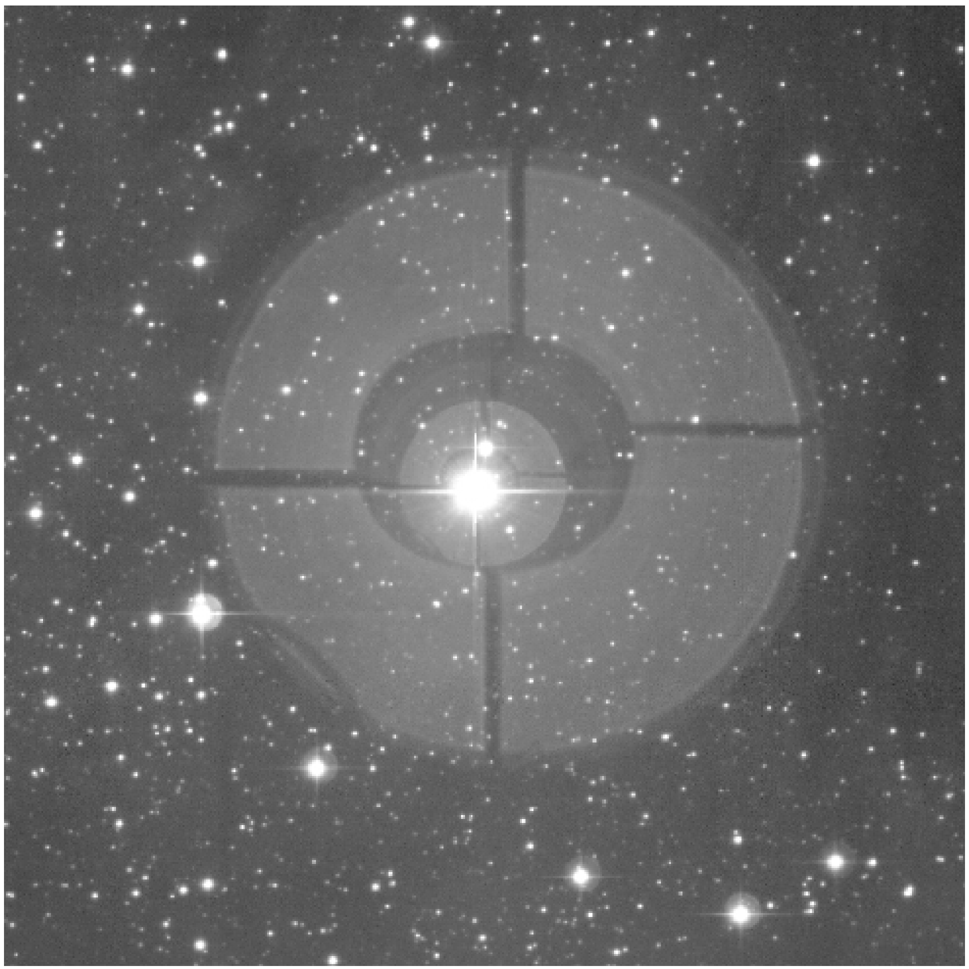
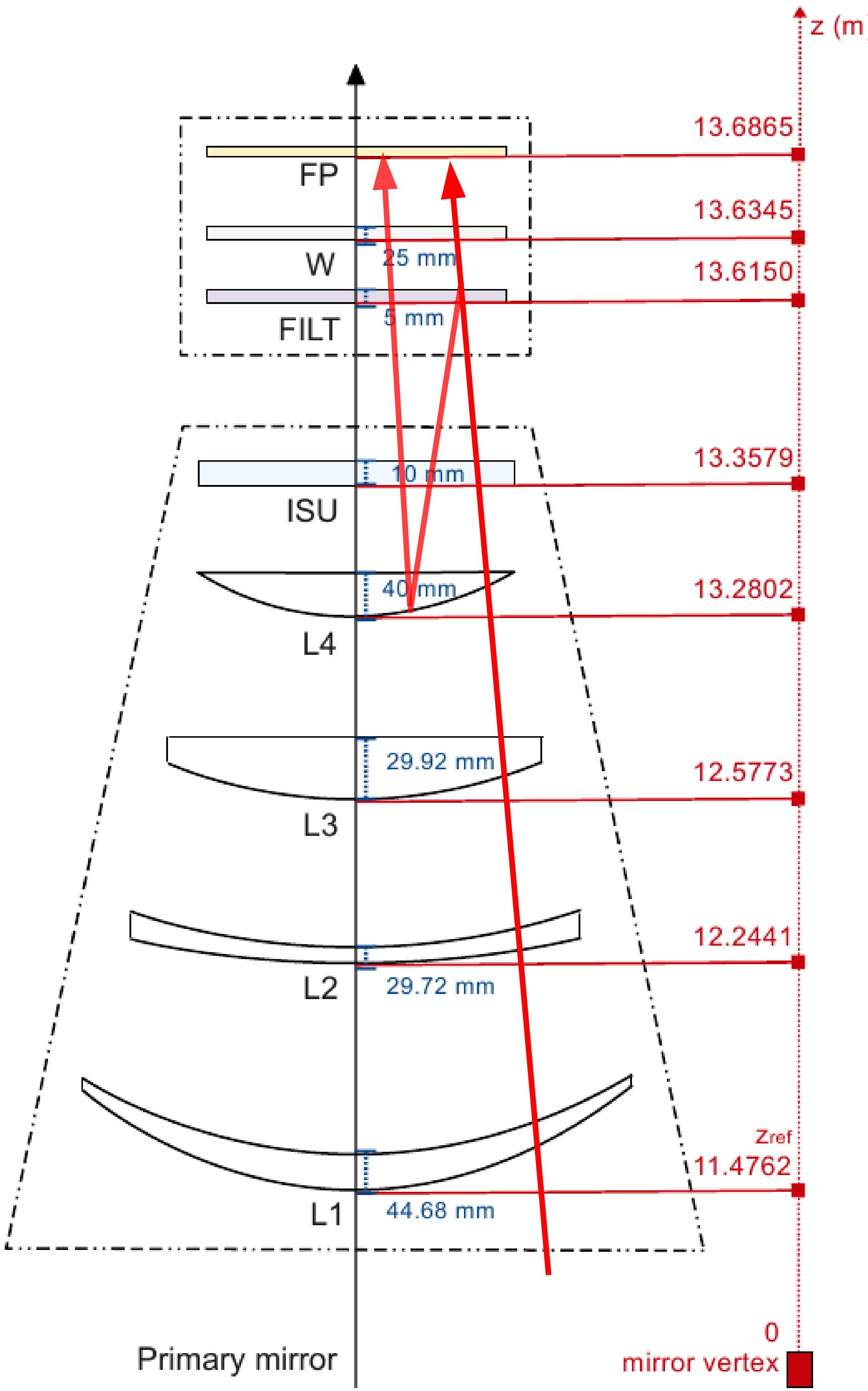
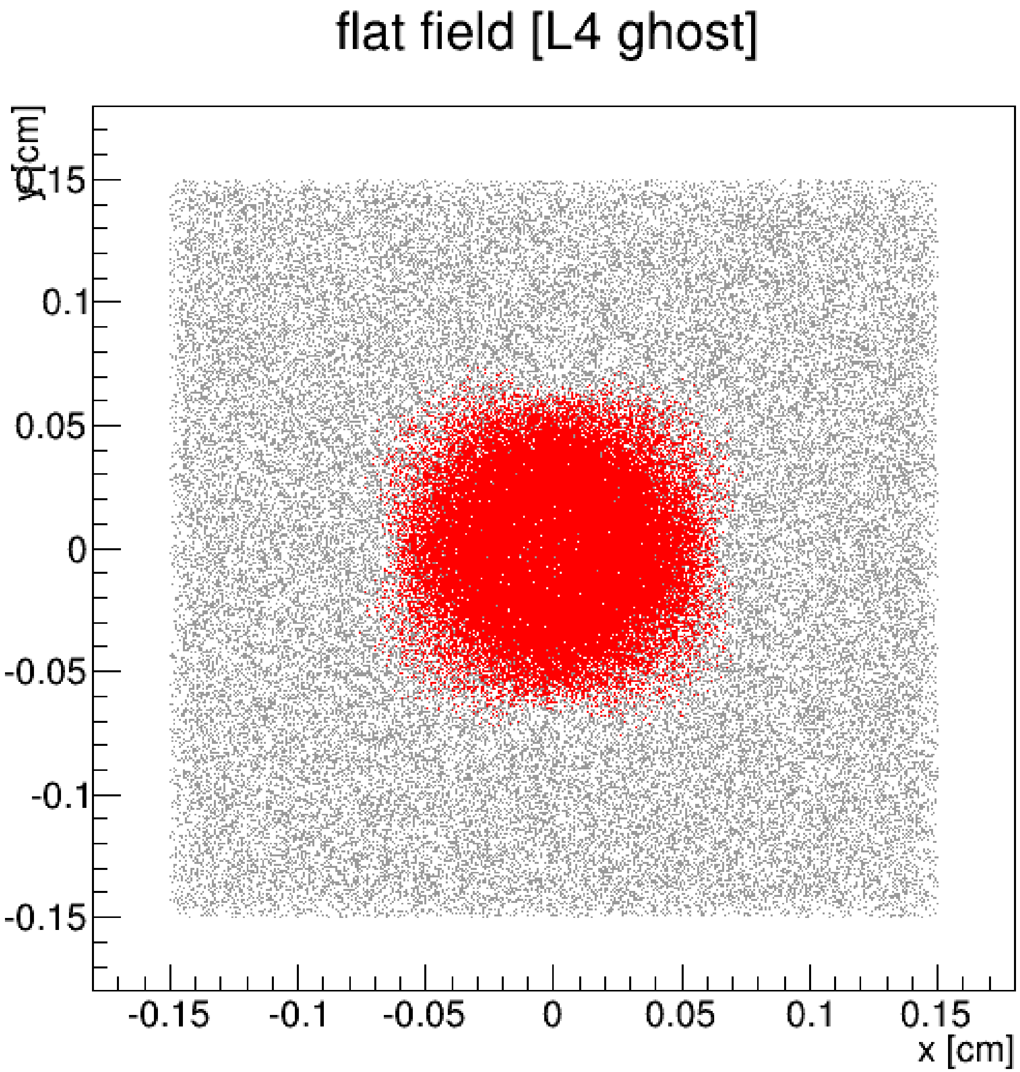
Instrument response



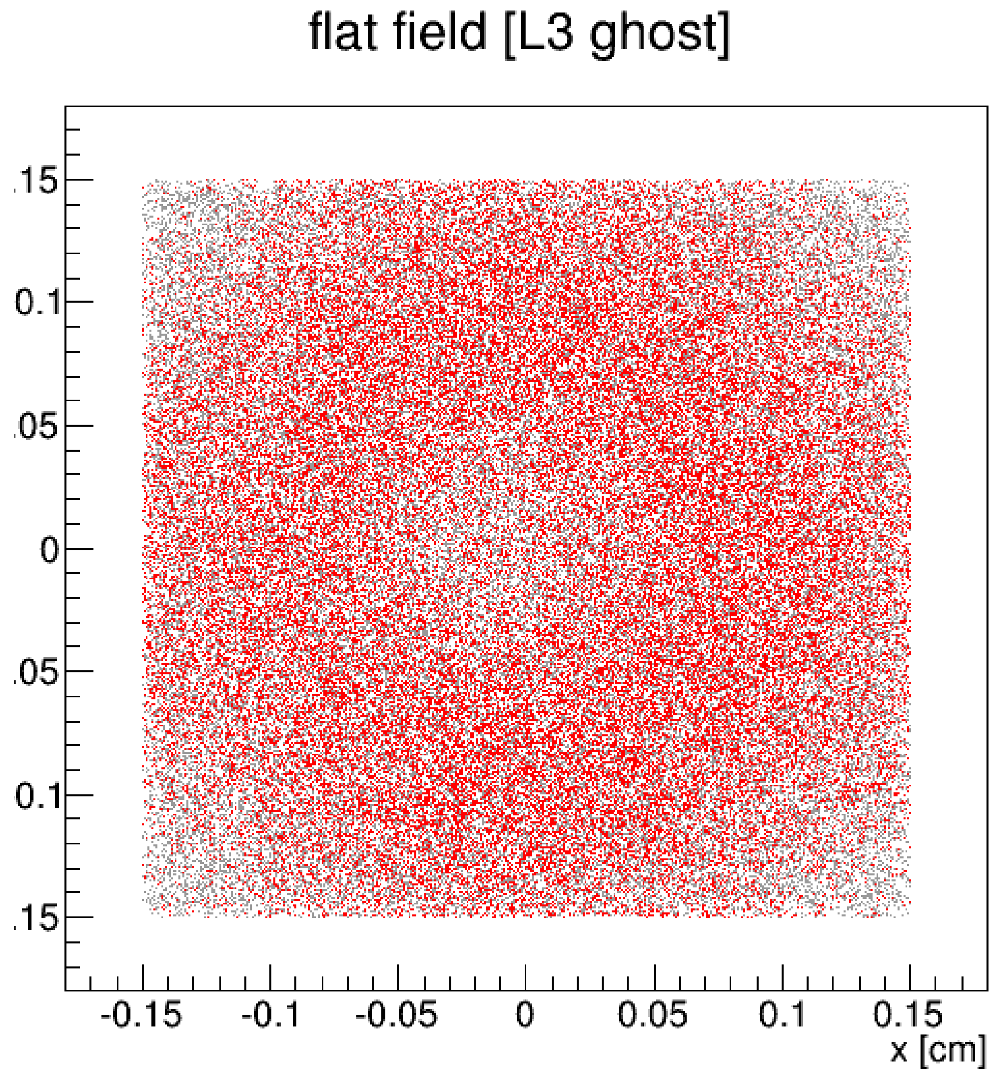
(Regnault et al, '09)
(Betoule et al, '13)

- Flat fields
  - Affected by plate scale variations (well measured)
  - contaminated by ghosts (reflections in the WFC)..
- Filter uniformity
  - MegaCam filters vary by ~ 5-nm from center to corner.


z (m)
13.6865
13.6345
13.6150
13.3579
13.2802
12.5773
12.2441
Zref
11.4762
0
mirror vertex
FP
W
25 mm
FILT
5 mm
ISU
10 mm
40 mm
L4
29.92 mm
L3
L2
29.72 mm
L1
44.68 mm
Primary mirror

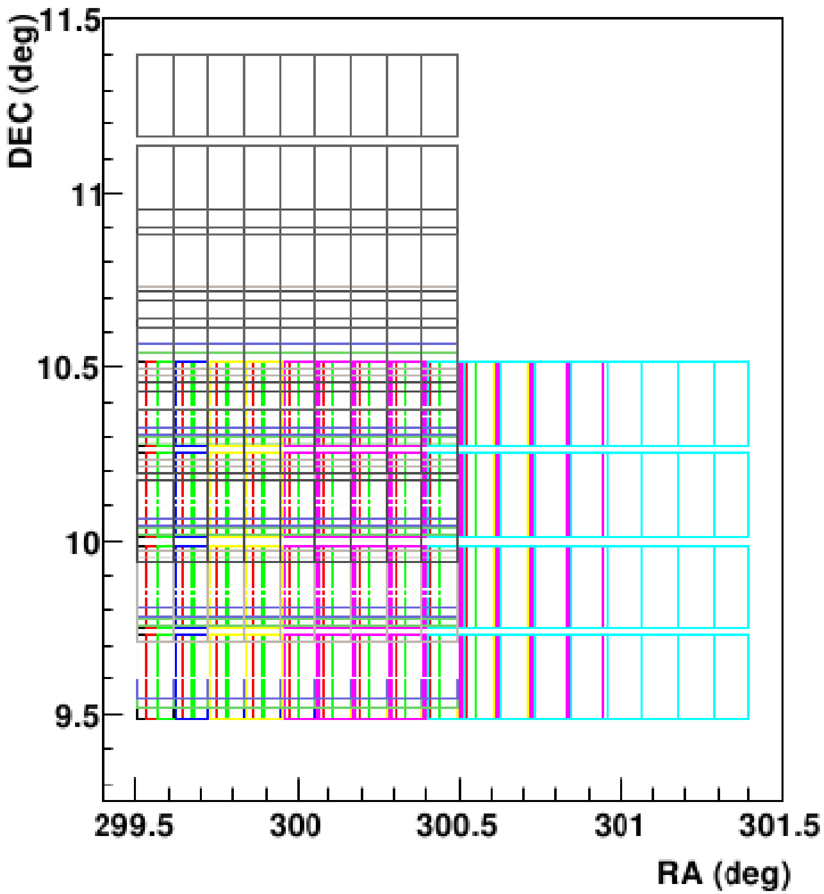


flat field [L4 ghost]
y [cm]
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x [cm]



flat field [L3 ghost]
.15
0.1
.05
0
.05
0.1
.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x [cm]

Mapping the instrument response



- Dithered observations of dense stellar fields
  - Logarithmically Increasing steps (1.5' ⟶ 0.5 deg)
  - Observed every ~ 6 months
- Model

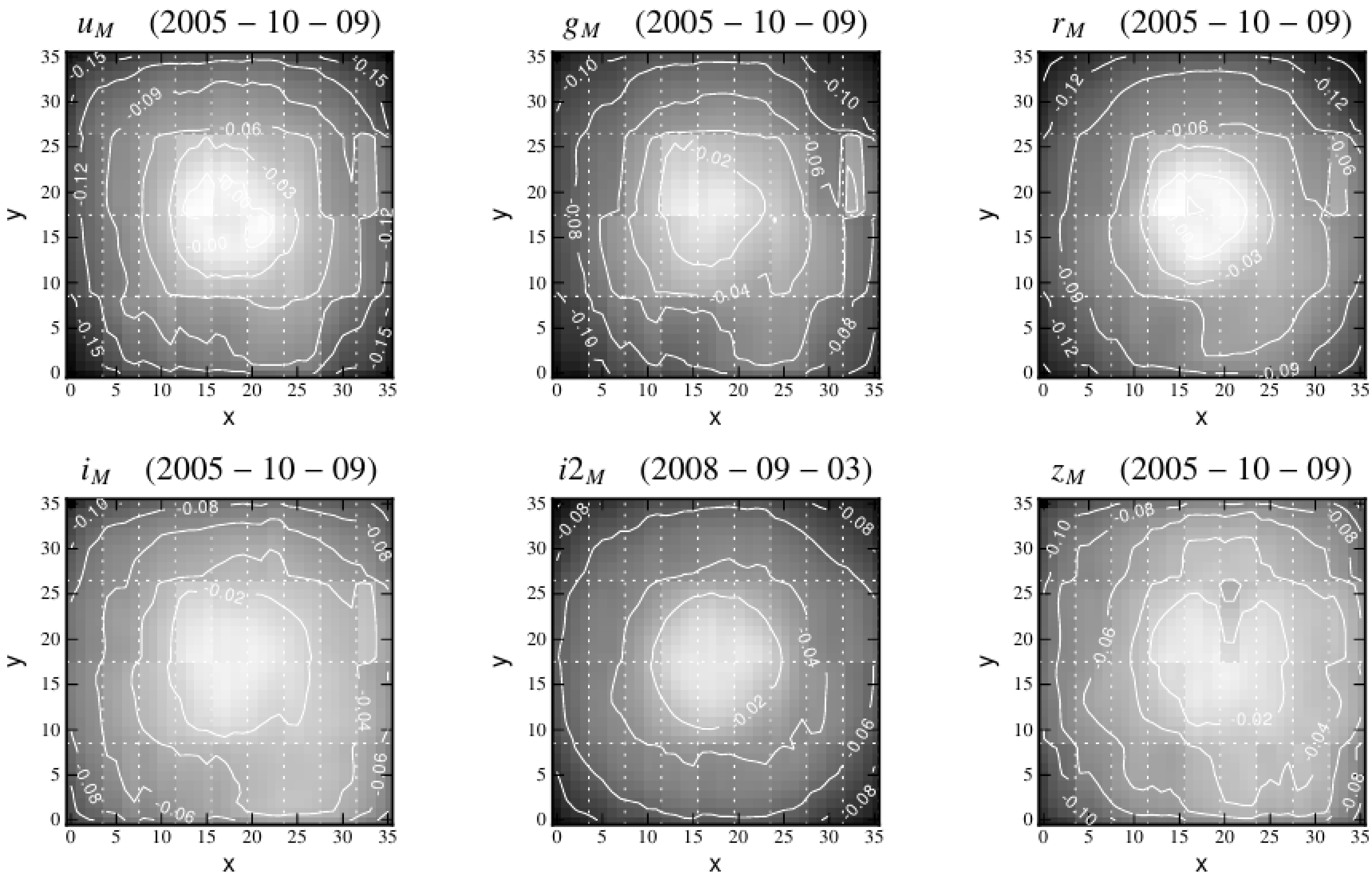
$$m(x) = m(x_0) + \delta zp(x) + \delta k(x) \times col$$

Star mags @ center
(~ 100,000 pars)

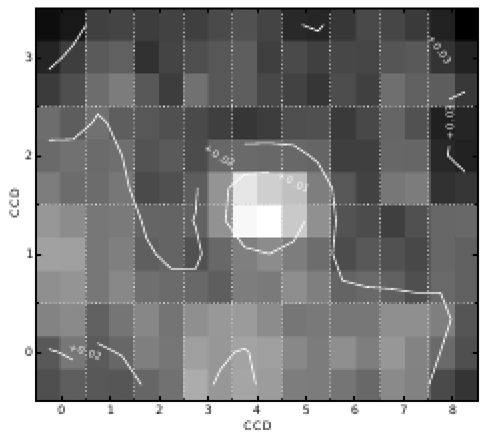
Maps
(~ 100 pars)

(Magnier & Cuillandre, 2004; Regnault et al, 2009)

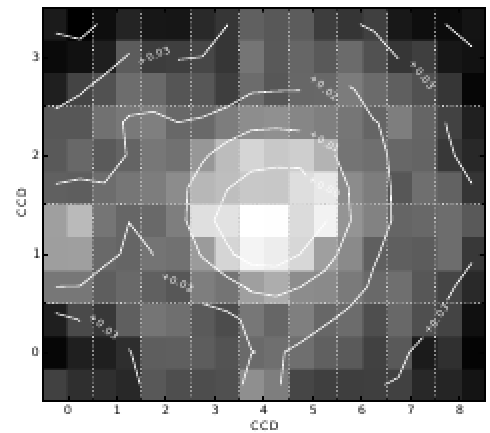
Plate scale + ghosts



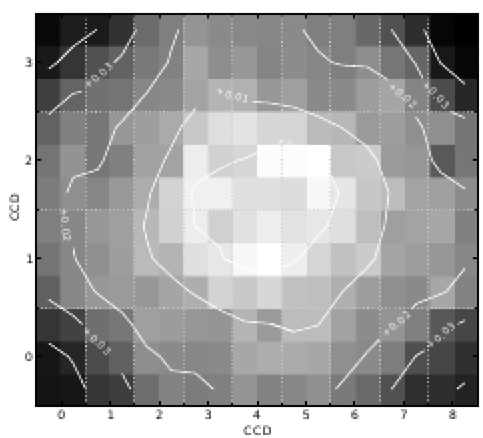
Filter variations (in λ)



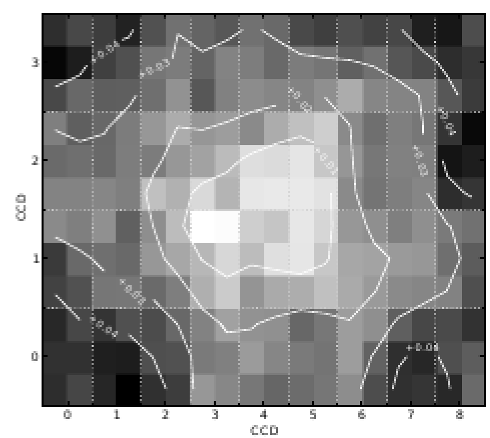
(a) $\delta k_{g,g-r}(\mathbf{x})$



(b) $\delta k_{r,r-i}(\mathbf{x})$



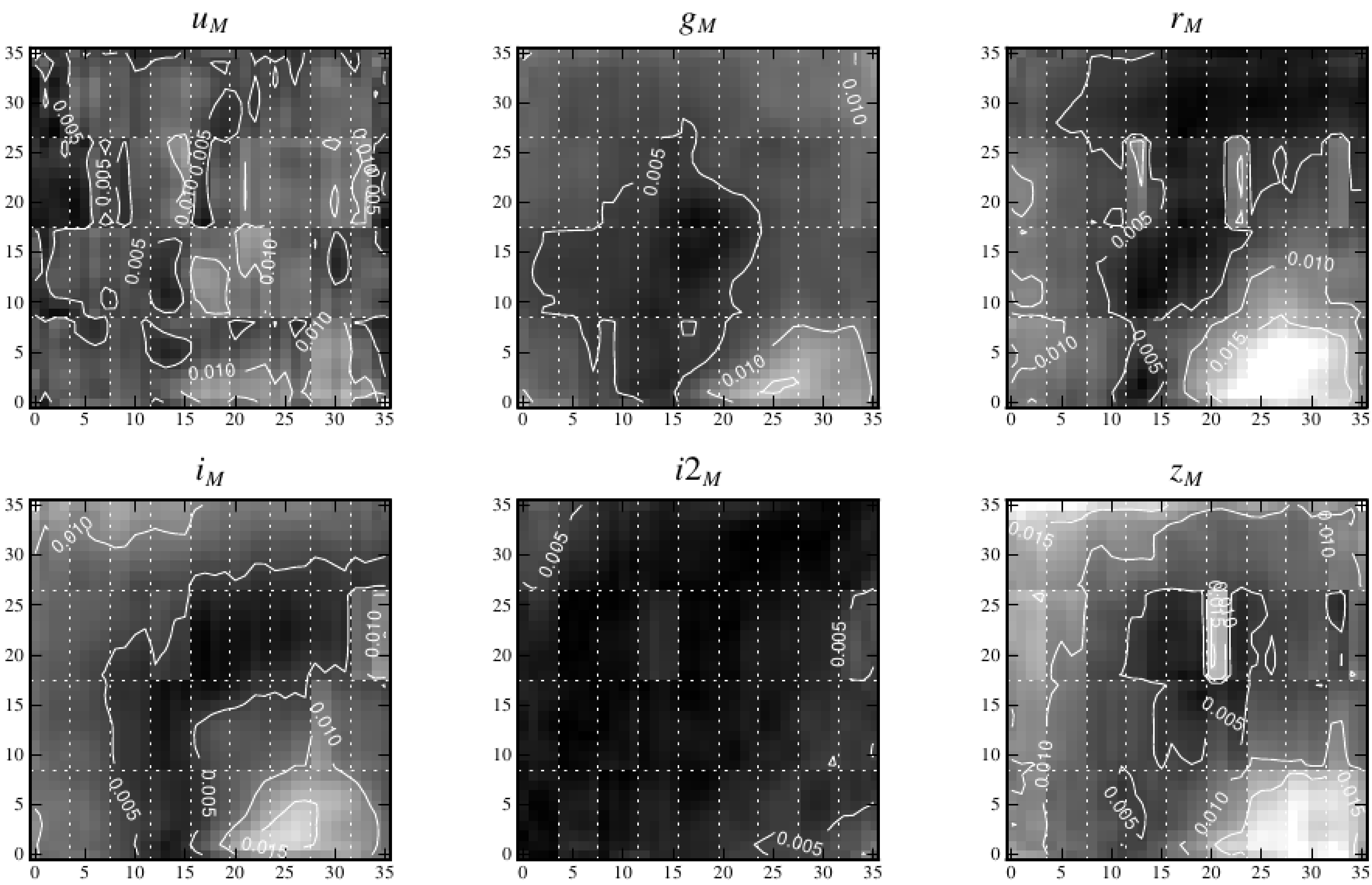
(c) $\delta k_{i,r-i}(\mathbf{x})$



(d) $\delta k_{z,i-z}(\mathbf{x})$

Preferable to measure the filters on a bench...)

Variability of the imager response



Uniformity

- Mapping techniques rely on sets of dithered observations which are
  - Costly in terms of observing time

    $\longrightarrow$ taken every ~ 6 months / 1 year
- BUT
  - ~ 1% variations observed, over ~ 6 months timescales
- Best solution is a mix of
  - dithered observations
  - instrumental monitoring of the uniformity (every week)
- Why not instrumental monitoring only ?
  - uniformity maps depend on flux estimator used...

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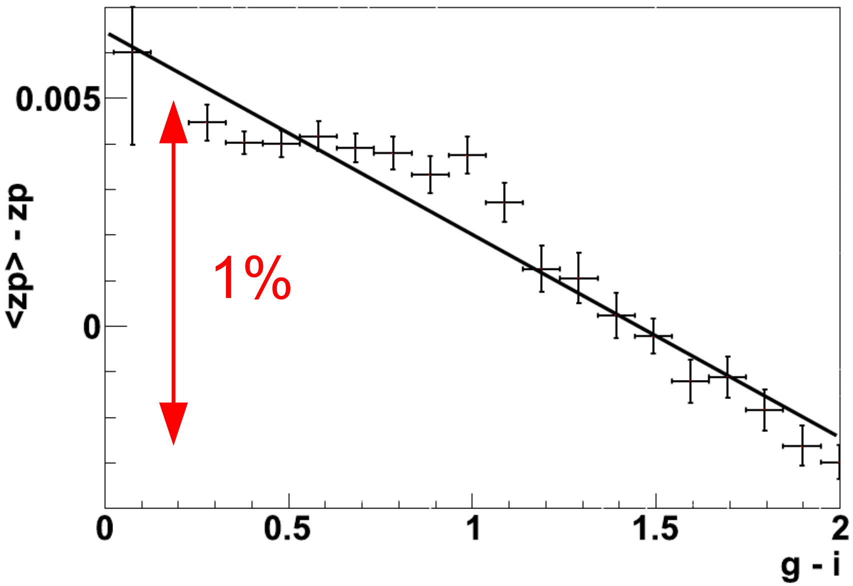
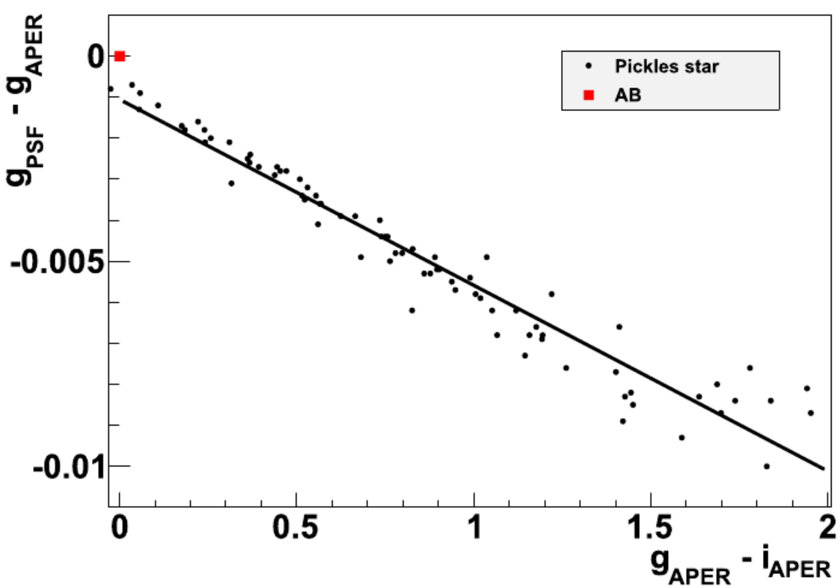
Precision PSF photometry

- Goals
  - 0.1% linearity in the mag range [18 – 24]
  - 0.1% precision (for bright sources)
- Many sources of bias at the 0.1% - level
  - Sky background estimates
  - PSF chromaticity
  - …
  - “Brighter fatter” effect (not an issue for MegaCam)
- See (Astier et al, 2013) for details

PSF CHROMATICITY



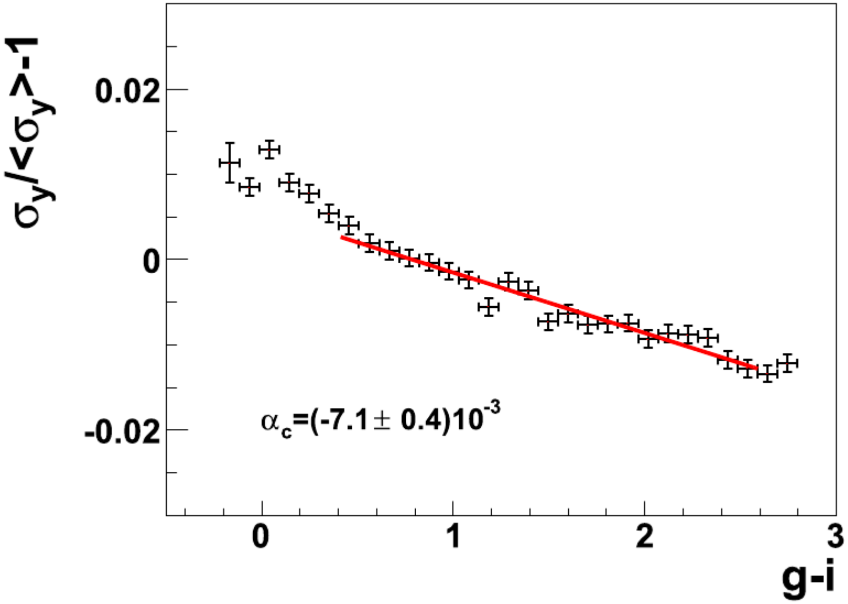


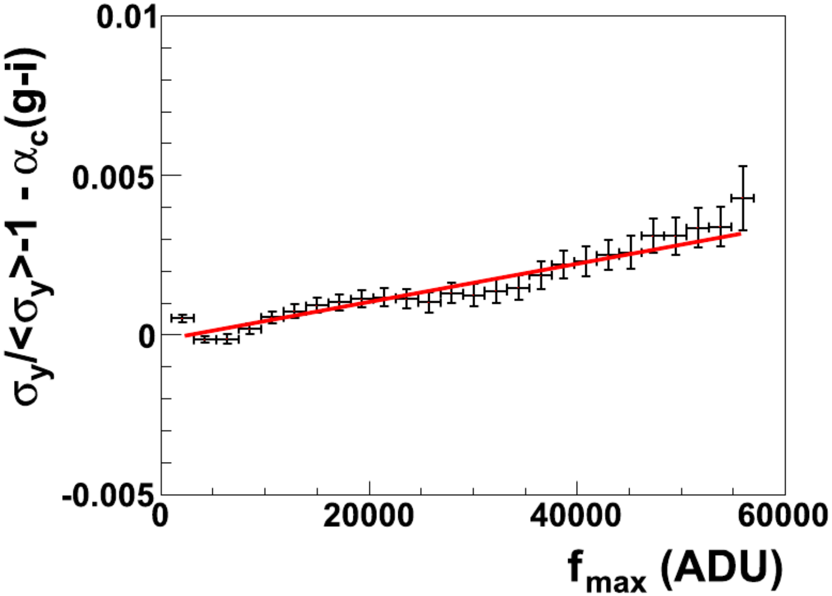
(Astier et al, 2013)

- PSF depends on star color !
- BUT
  - One PSF model / exposure
  - flux estimator depends on color
- Two possible solutions
  - Either build a chromatic PSF
  - Or alter the filter shapes

$$-2.5\log_{10}\frac{\int S(\lambda)T(\lambda)C(\lambda)\lambda d\lambda}{\int S_{AB}(\lambda)T(\lambda)C(\lambda)\lambda d\lambda}$$

Brighter-Fatter





- Effect detected on MegaCam exposures
  - small (<0.4% on full range)
- Two solutions
  - alter the pixels (unscrambling)
  - Incorporate the effect in PSF model
- For MegaCam

  flux bias ~ 3 x 10^{-4}

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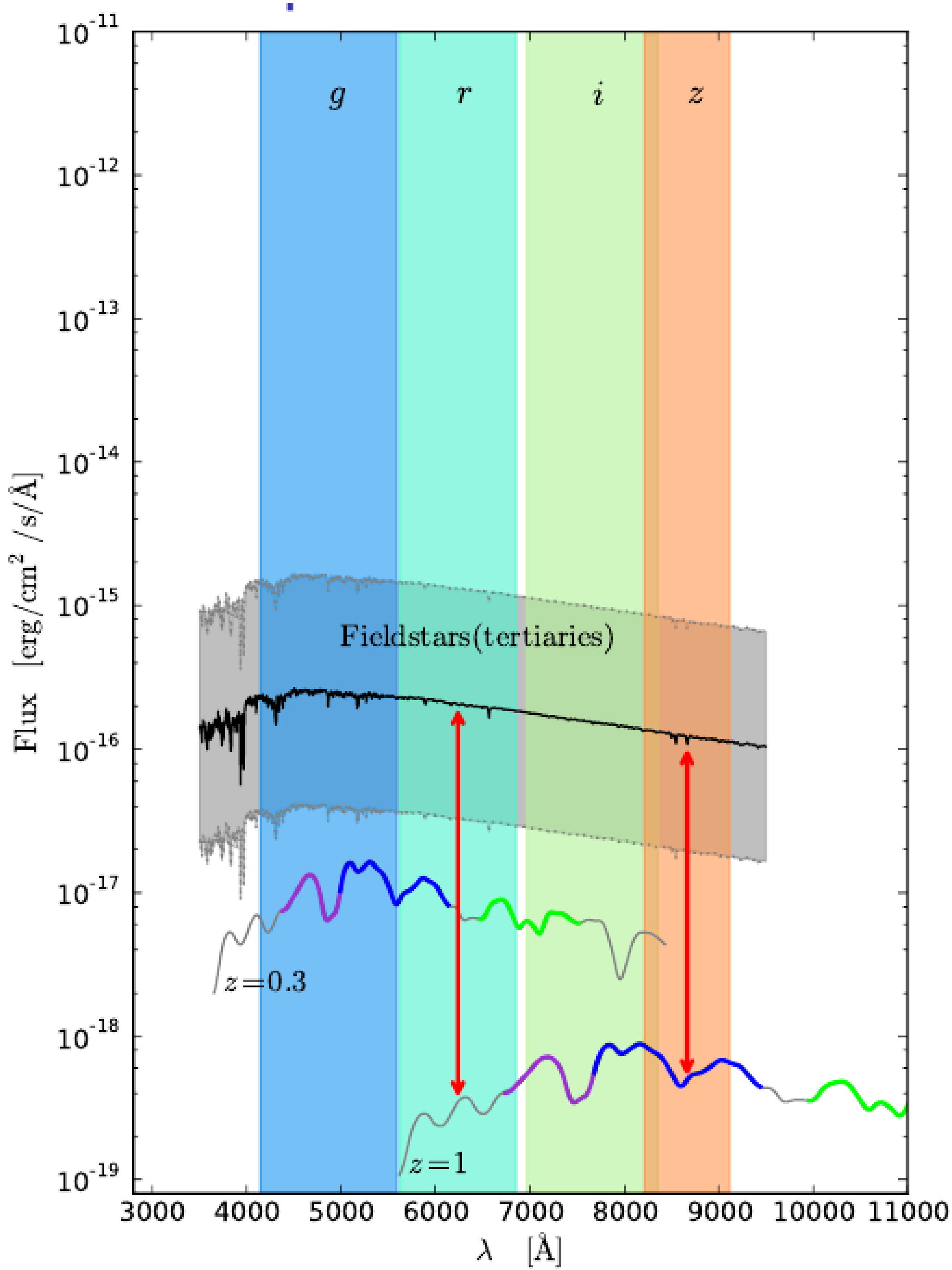
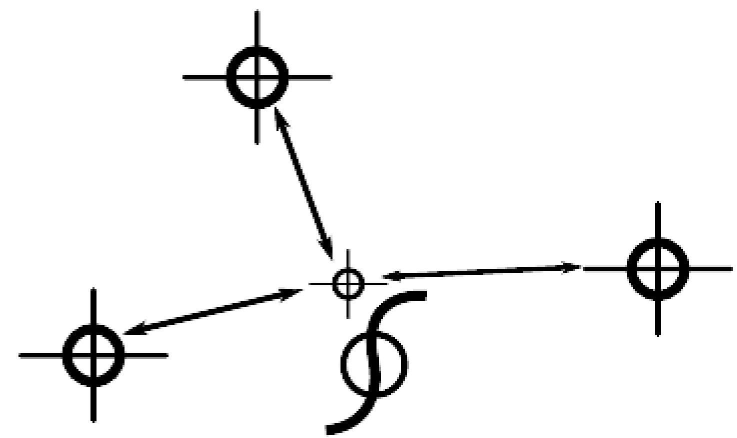
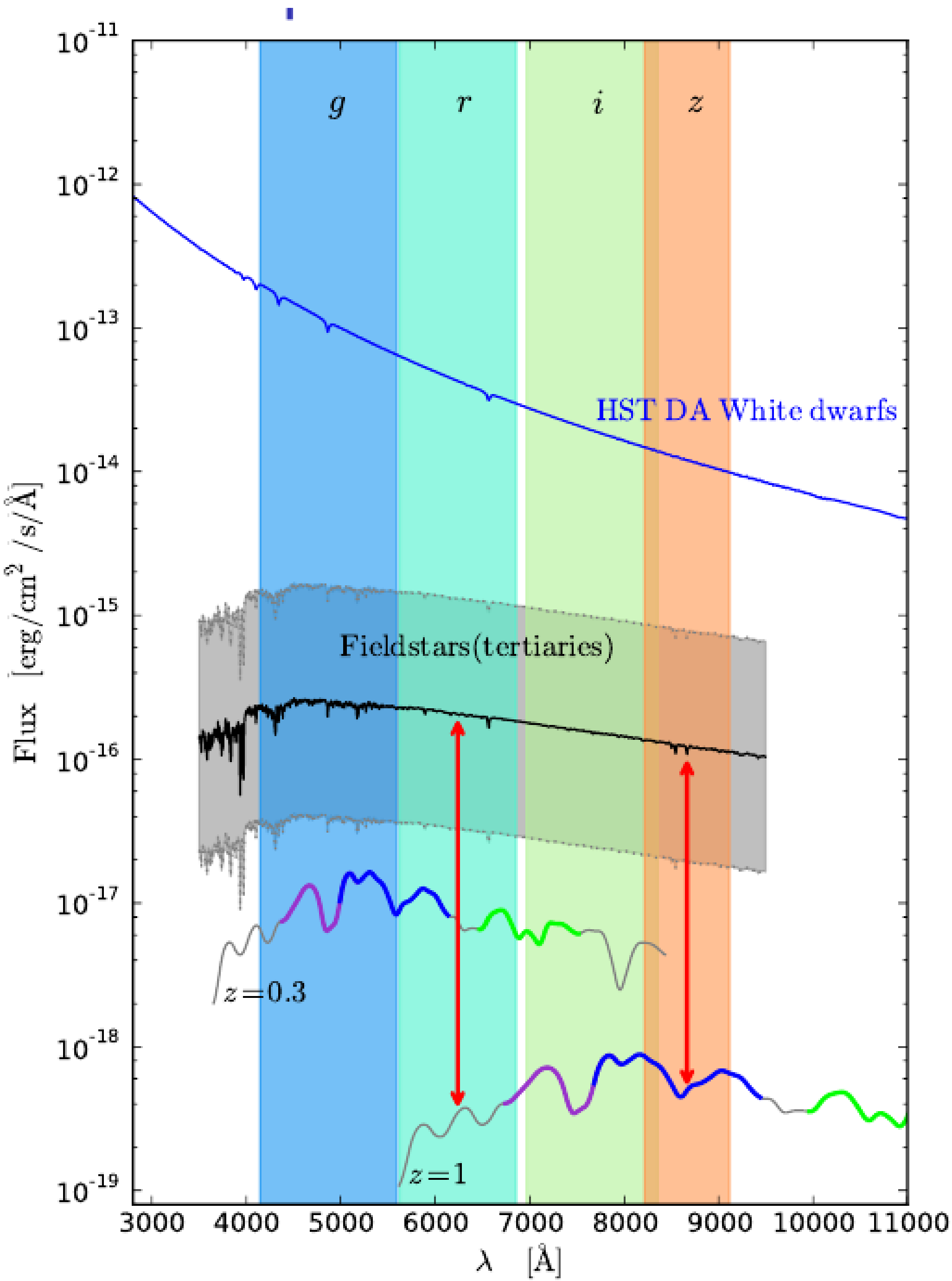
Flux metrology chain



- Instrument response
  - Measure flux ratios in a single image



Flux metrology chain



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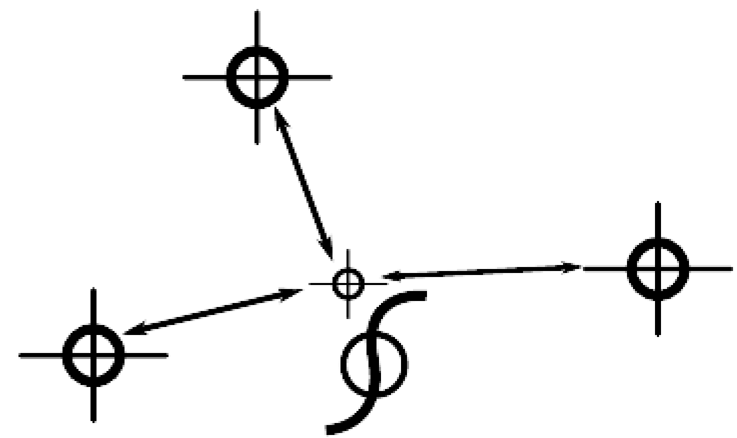
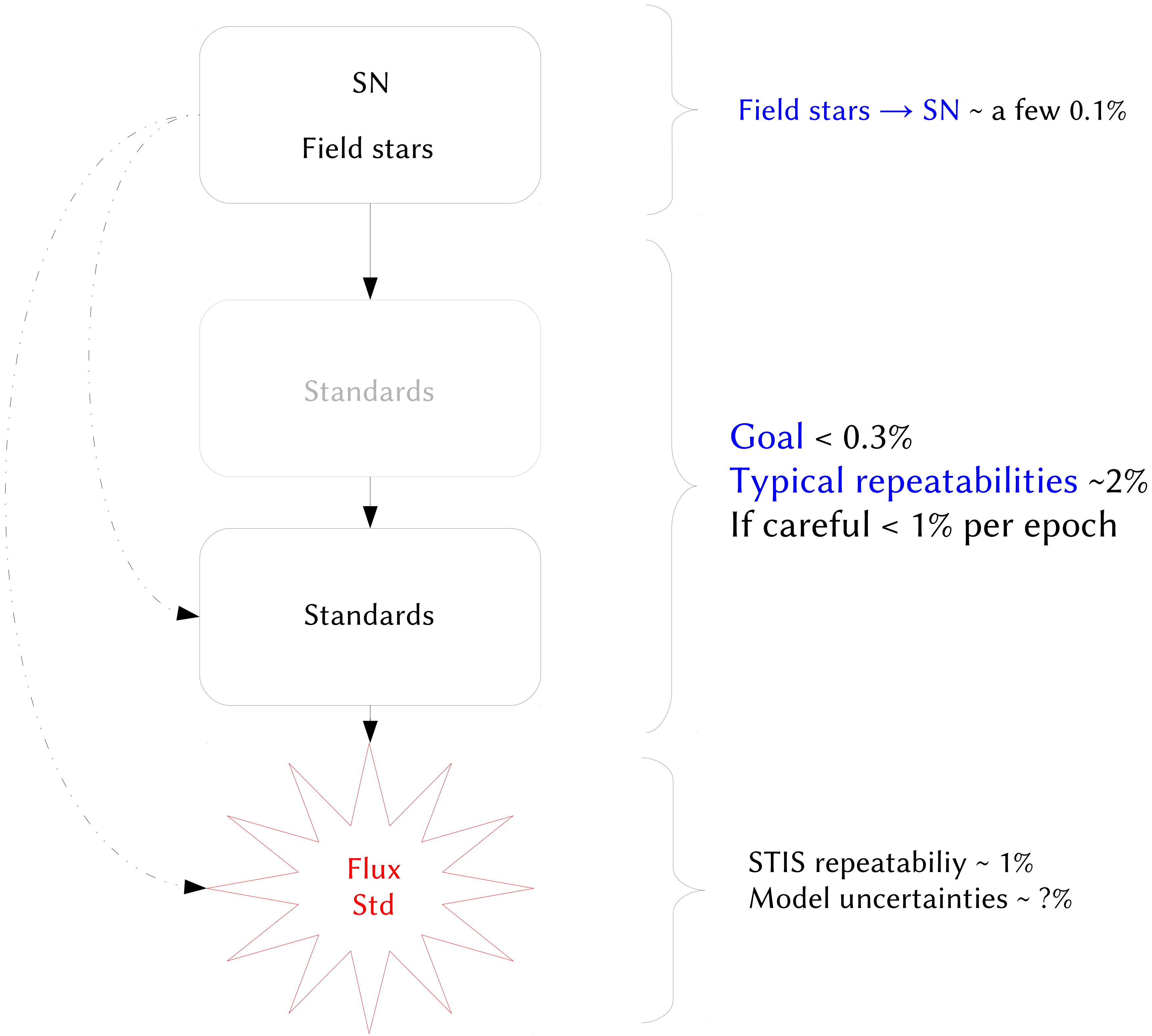
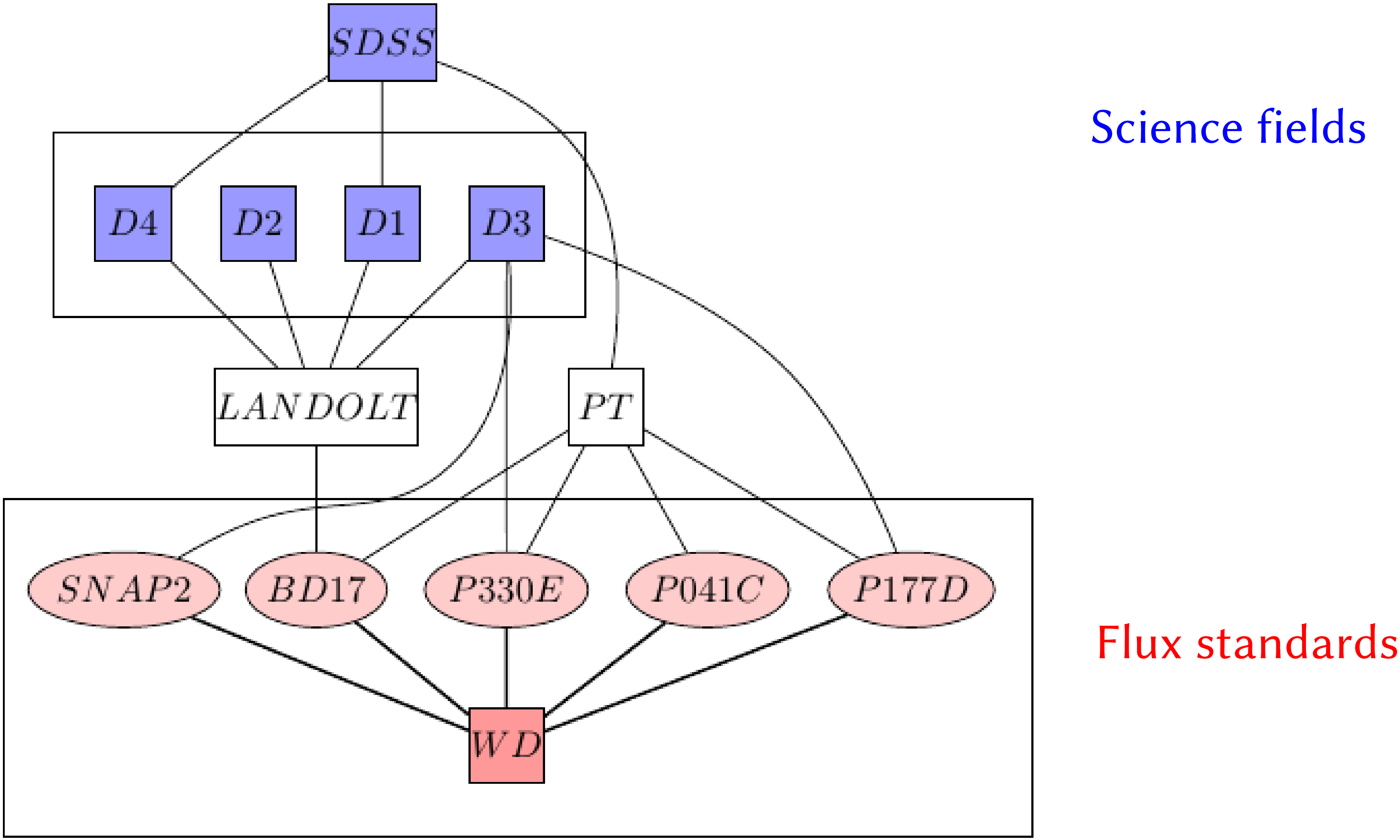


- Calibration transfer
  - HST standard as a primary calibration flux

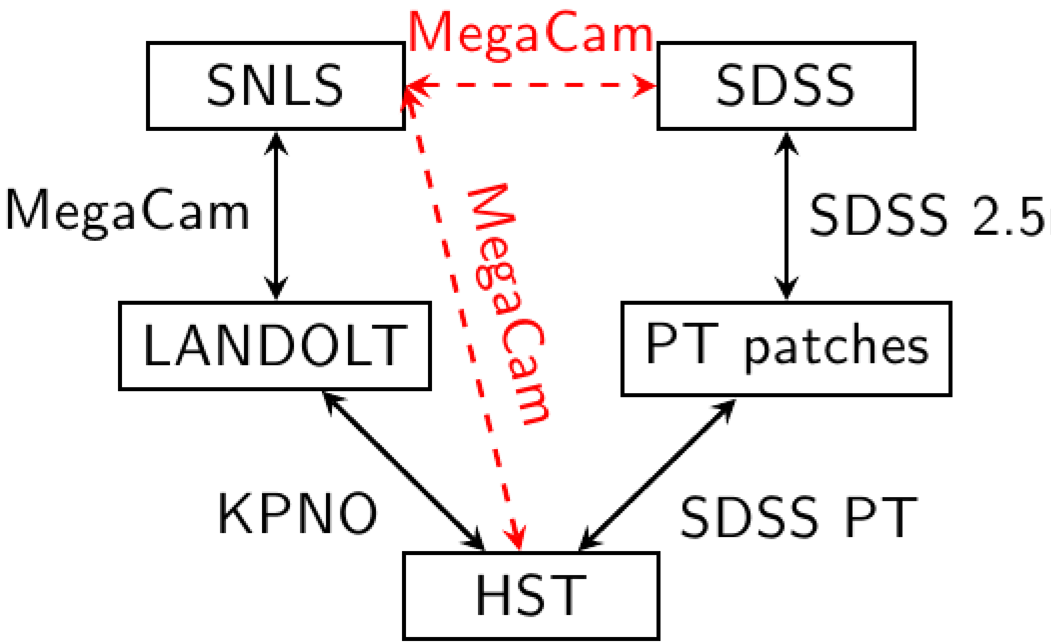


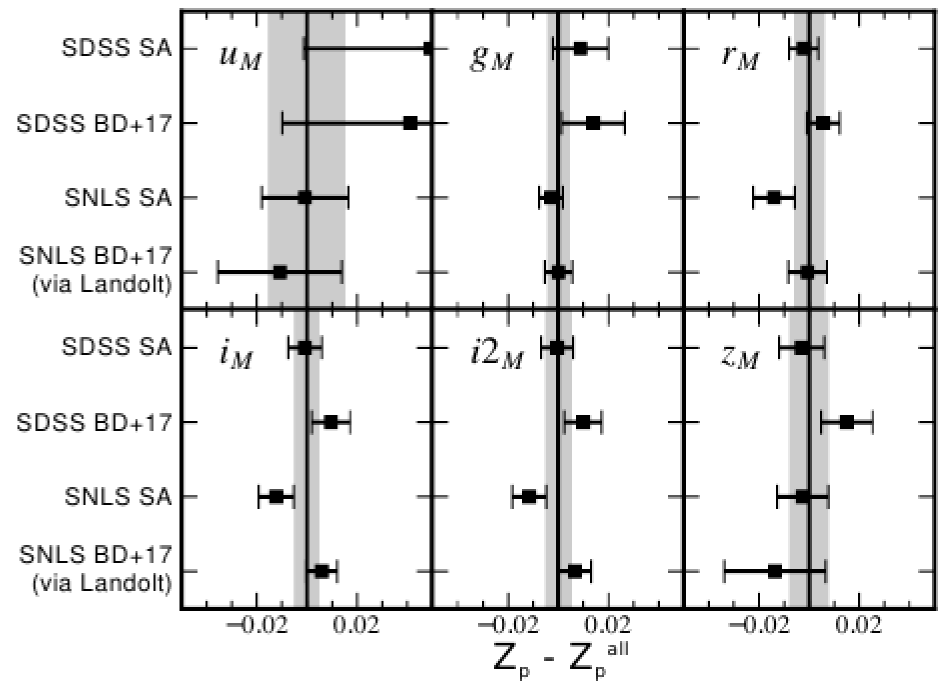
SN
Field stars
Standards
Standards
Flux
Std
Field stars → SN ~ a few 0.1%
Goal < 0.3%
Typical repeatabilities ~2%
If careful < 1% per epoch
STIS repeatabiliy ~ 1%
Model uncertainties ~ ?%



(Betoule et al, 2014)

SNLS/SDSS (JLA) calibration paths





- Direct observations of SDSS & HST stars
- Several calibration paths
- 0.3% accuracy in gri

(Betoule et al, 2013)

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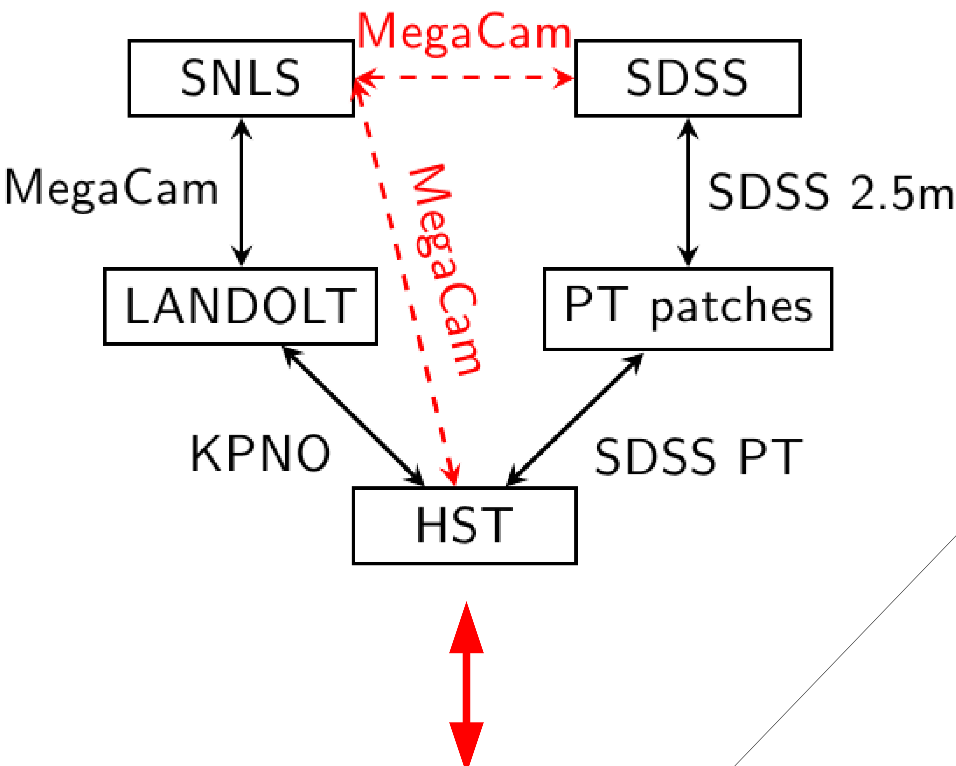
Instrumental calibration



Hamamatsu S2281

- Stellar flux standards

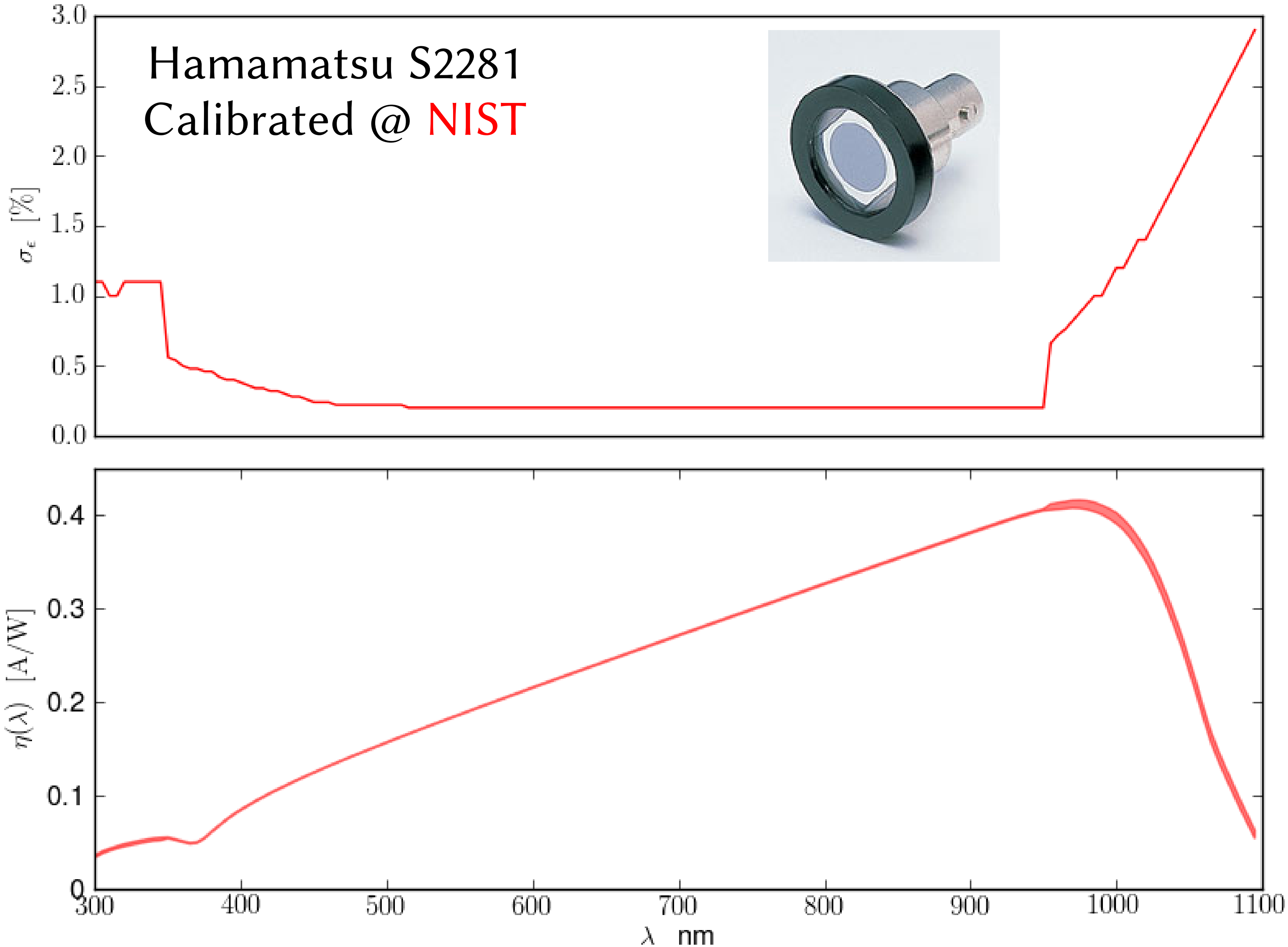
  vs

  Laboratory standards

- Precision monitoring of large focal planes

- 0.1% calibration accuracy

Switching to a Lab Standard



A new metrology chain

DETECTORS | SOURCES

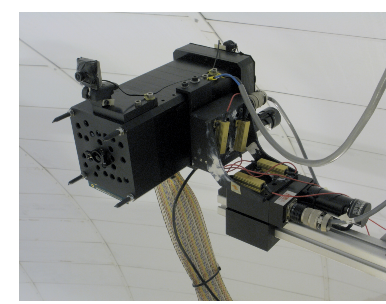
POWR (NIST)
(Houston & Rice 2006)

SIRCUS/SCF (NIST)
(Brown et al. 2006, 2000)
(Larason & Houston 2008)

Calibrated
Si photodiode

❶

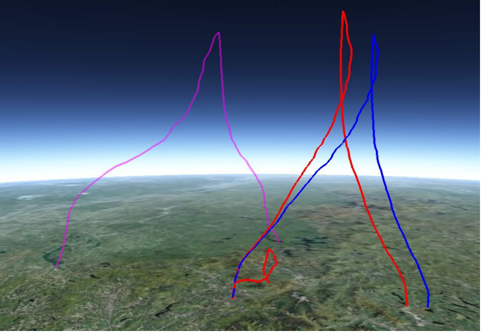
Calibrated source
(in the telescope enclosure)



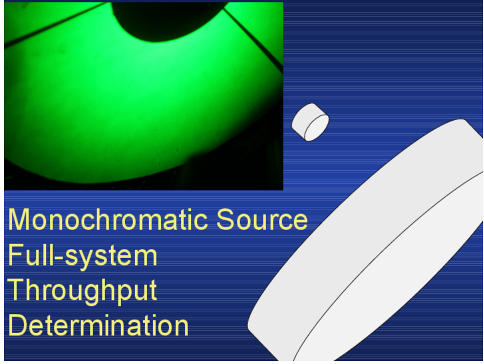
❷

Imager

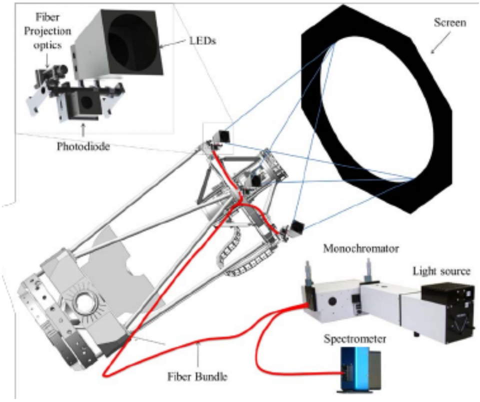
Back to the stars...

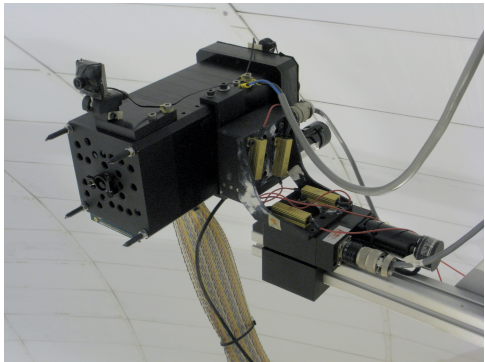


Calibration Projects

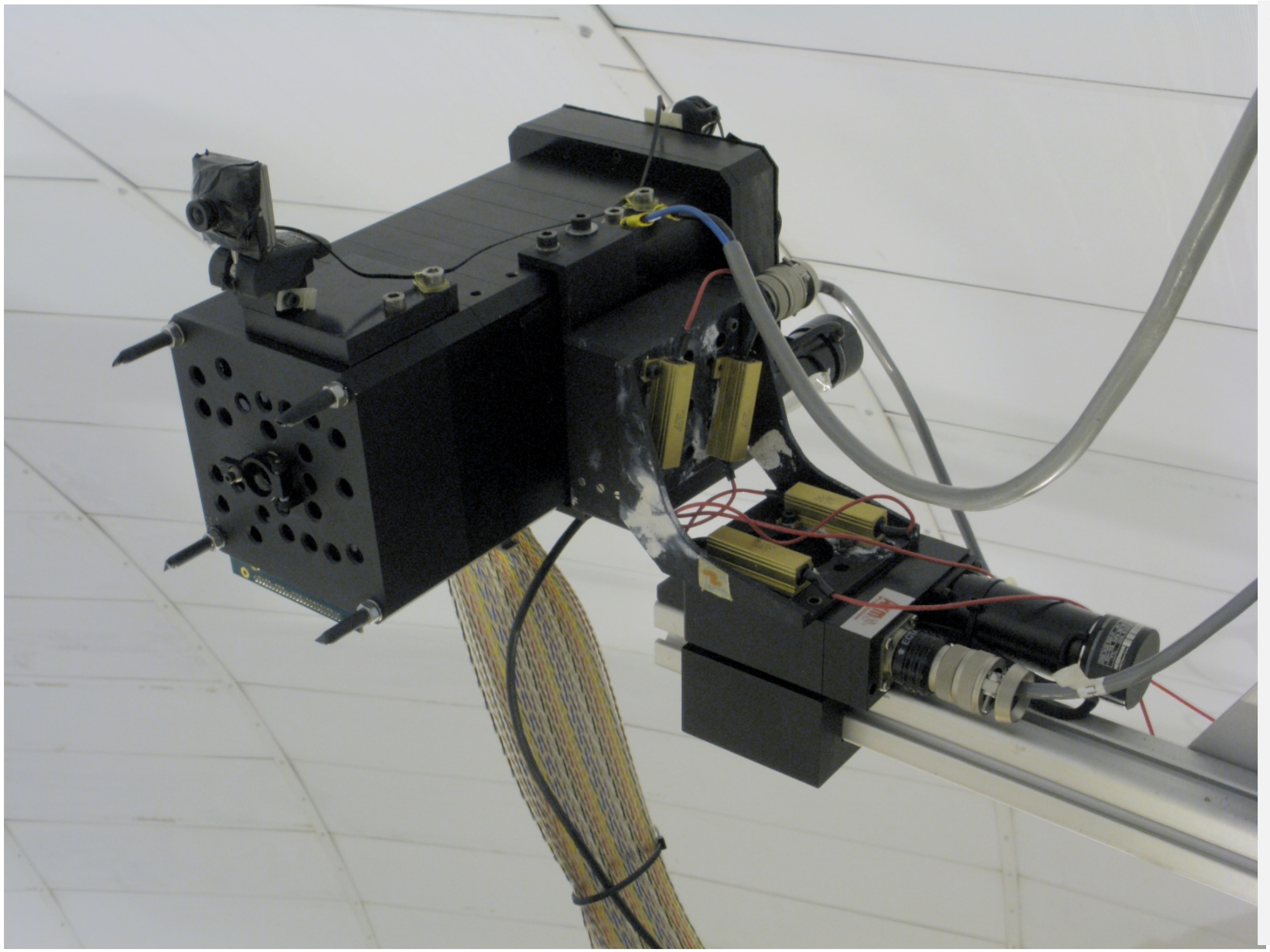


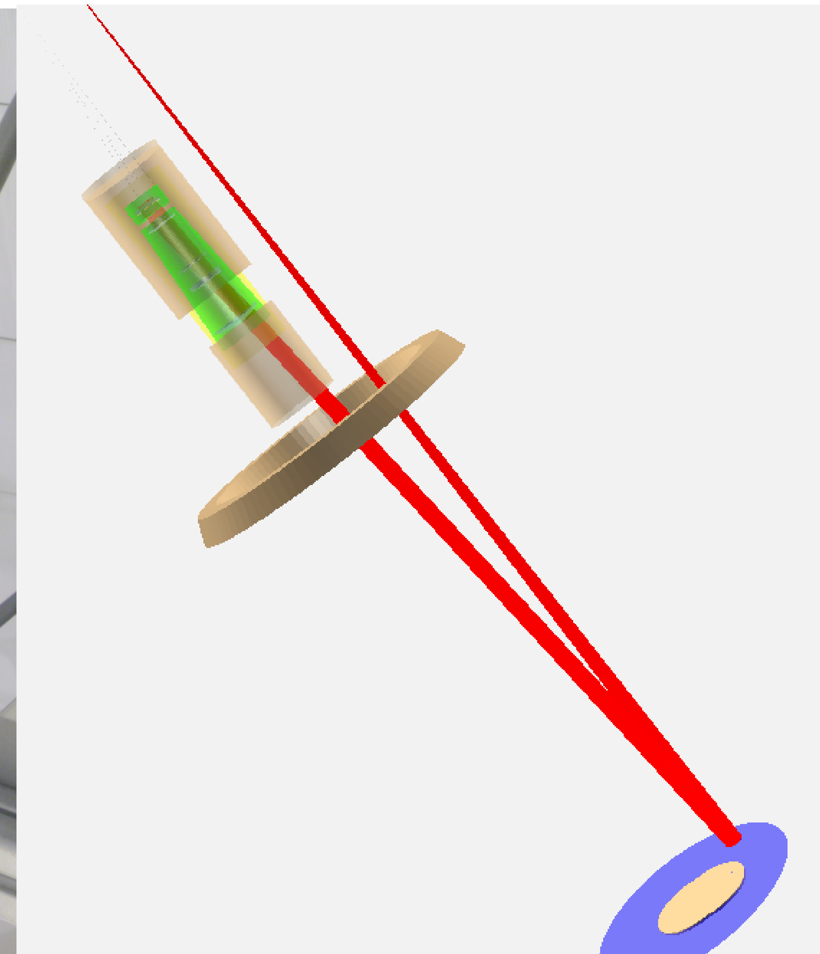
- Harvard (Stubbs et al)
  - ESSENCE
  - PanSTARRS
- Texas A&M (DePoy et al)
  - DES (Dark Energy Survey)
- NIST (Cramer et al)
  - Artificial star ⟶ recalibration of Vega
- ACCESS (Kaiser et al)
  - Small rocket-borne telescope (IR spectrophotometry)
- LPNHE
  - SnDICE (MegaCam)
  - SkyDICE (SkyMapper)



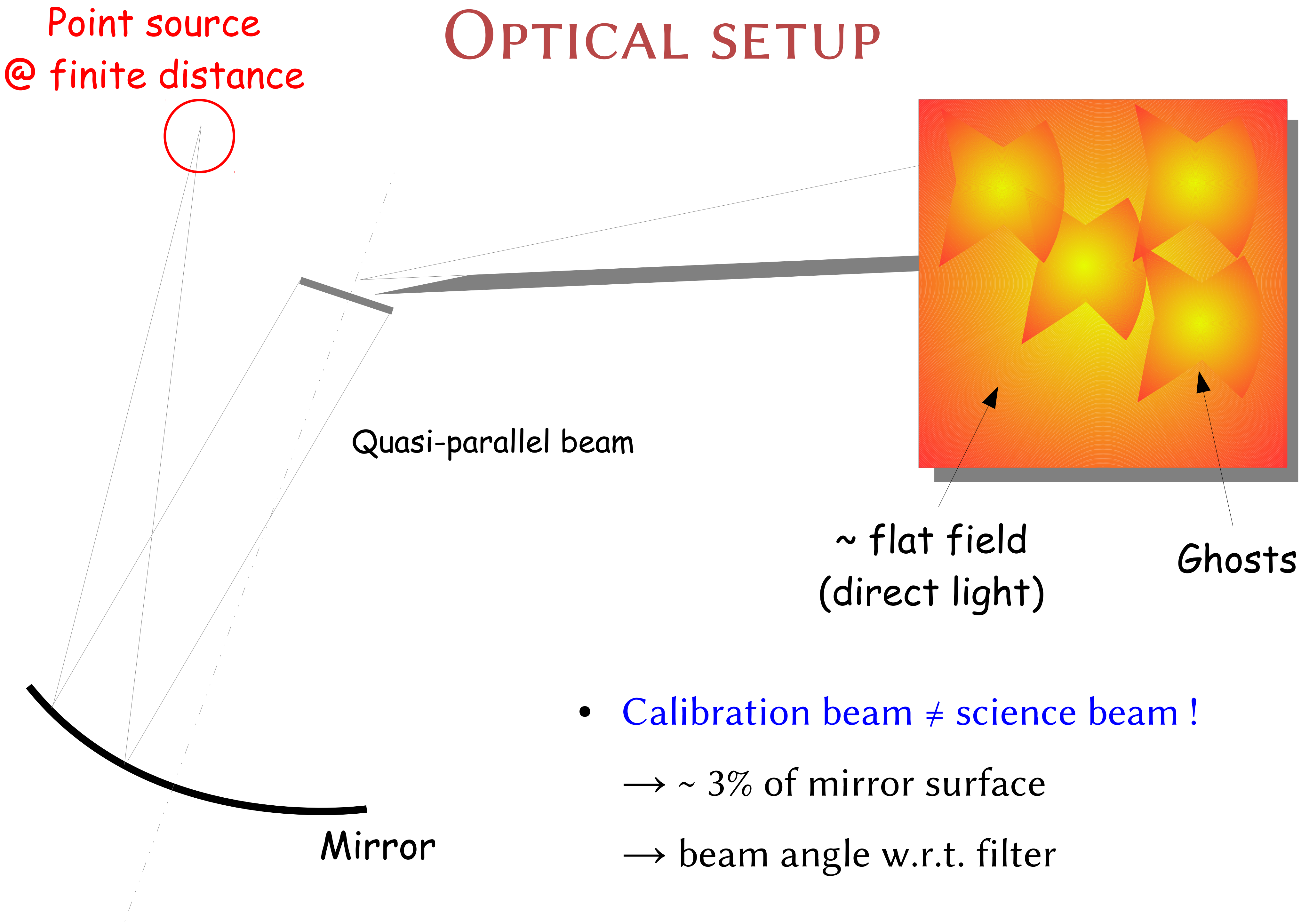


DICE : a stable LED source





Optical setup

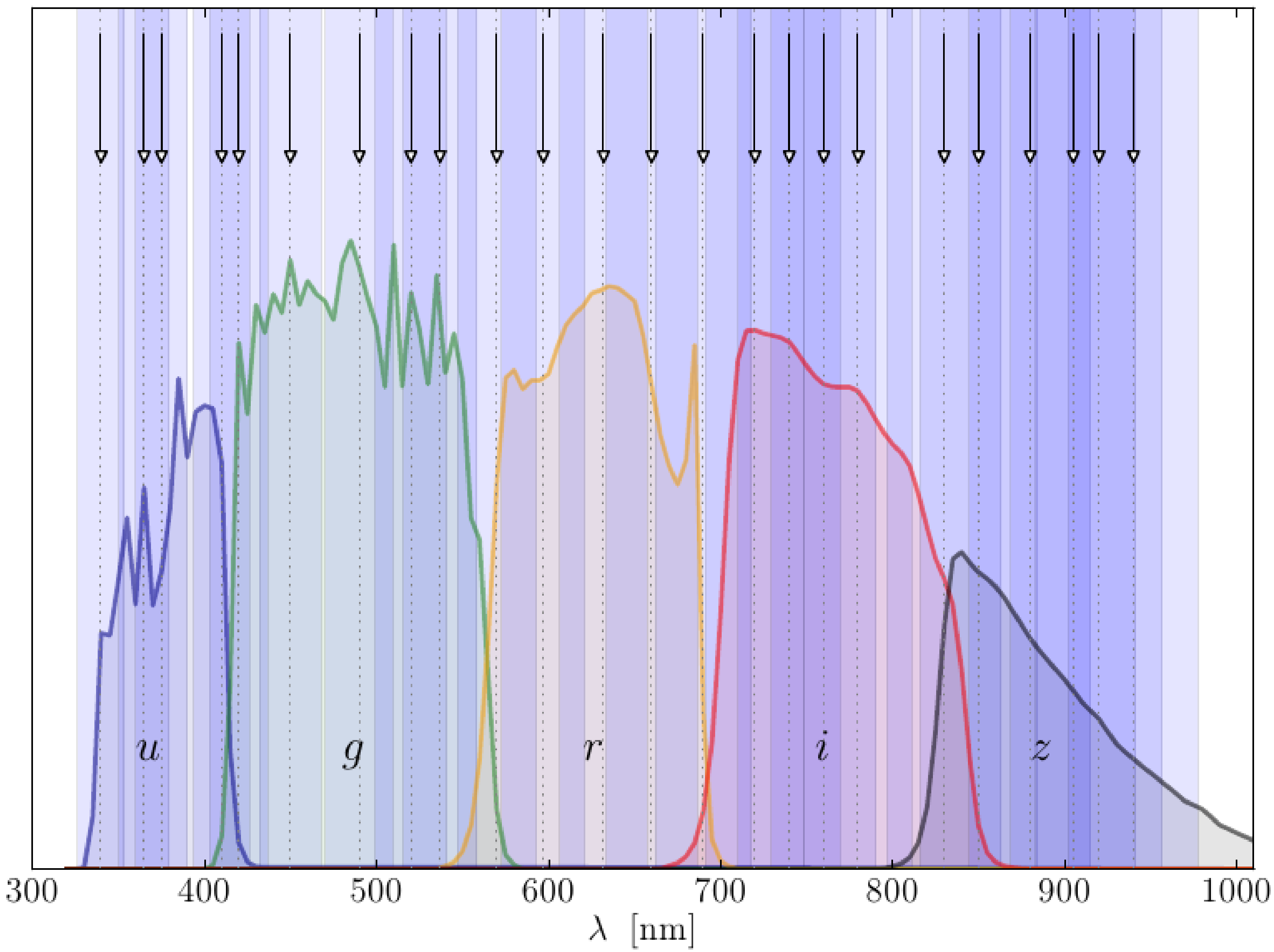


- Calibration beam ≠ science beam !

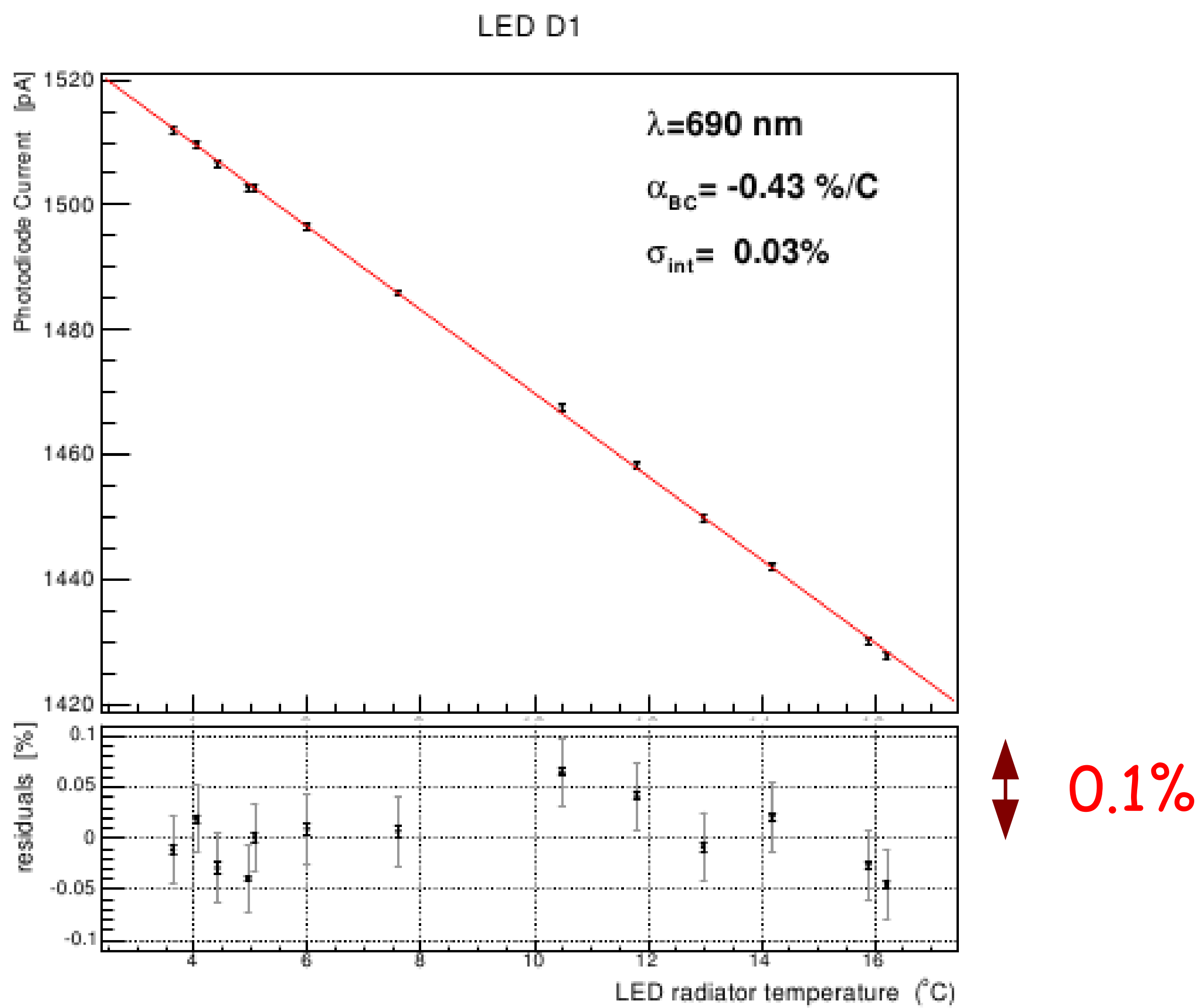
→ ~ 3% of mirror surface

→ beam angle w.r.t. filter

Typical LED coverage

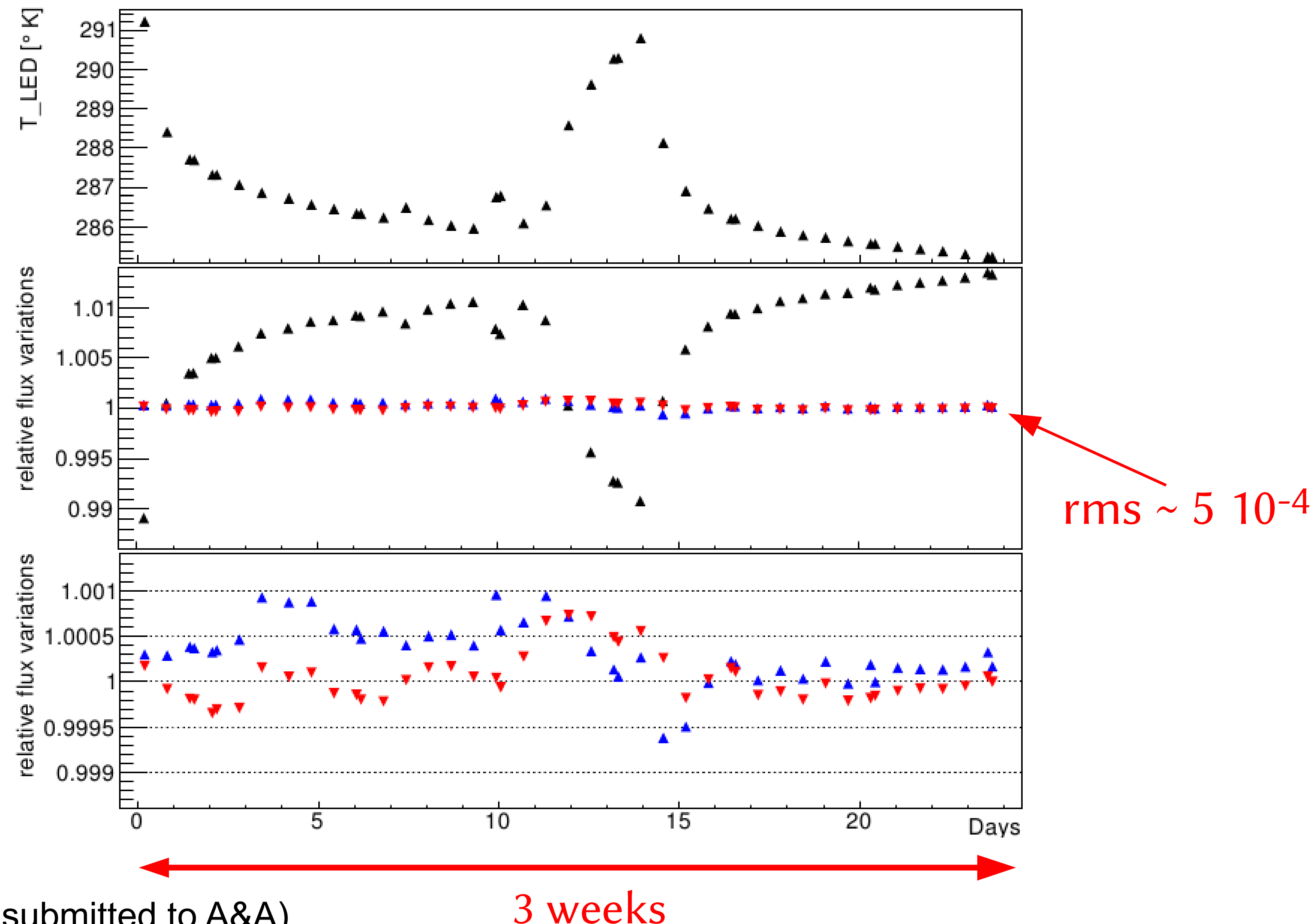


The "Cooler-brighter effect"



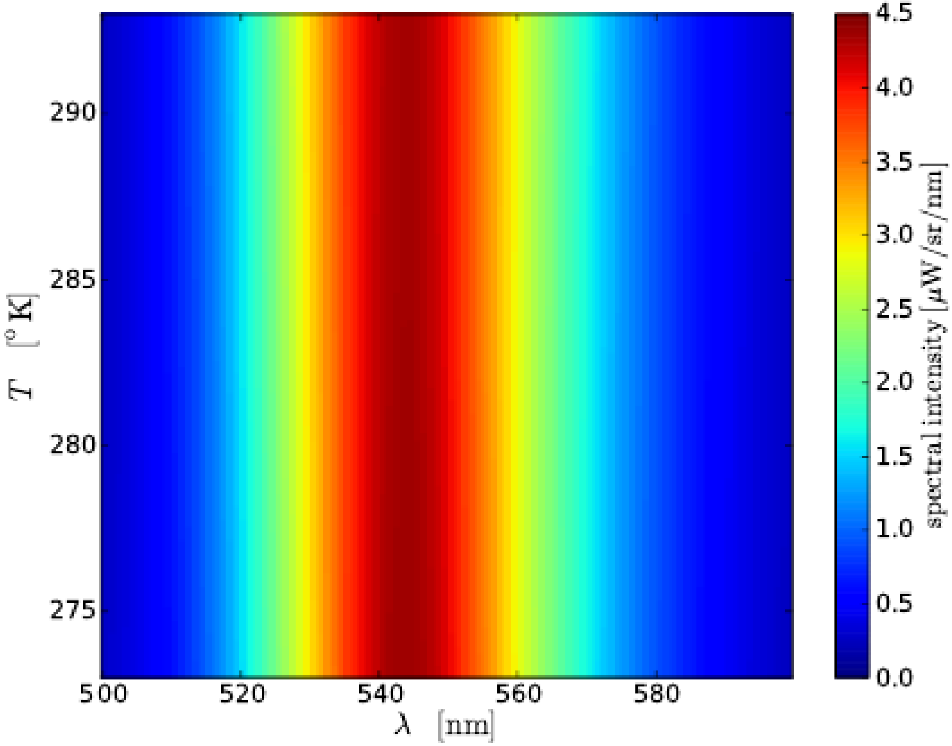
About 0.5% / °C for all LEDs

Long term stability studies

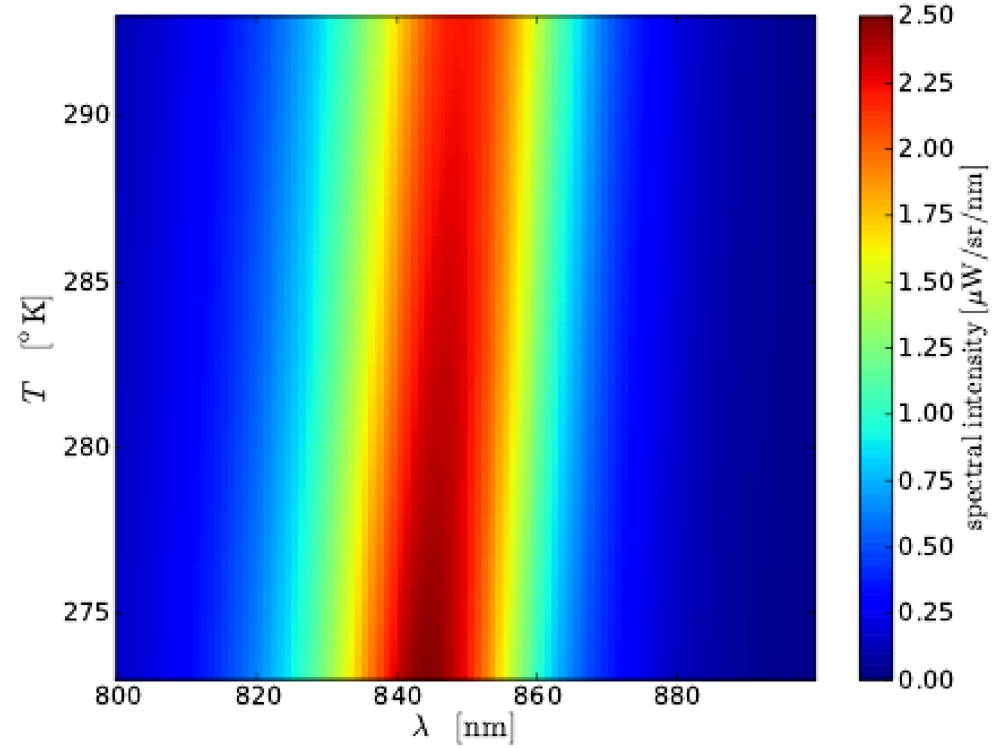


(Regnault et al, submitted to A&A)

A Spectrophotometric model for the LED source



(a) Golden Dragon® LT W5SM



(b) APG2C1-850 (Roithner LaserTechnik)

Predicts the LED spectral intensity (watts / sr / nm)
in a range of temperature ($0^{o}C < T < 25^{o}C$)

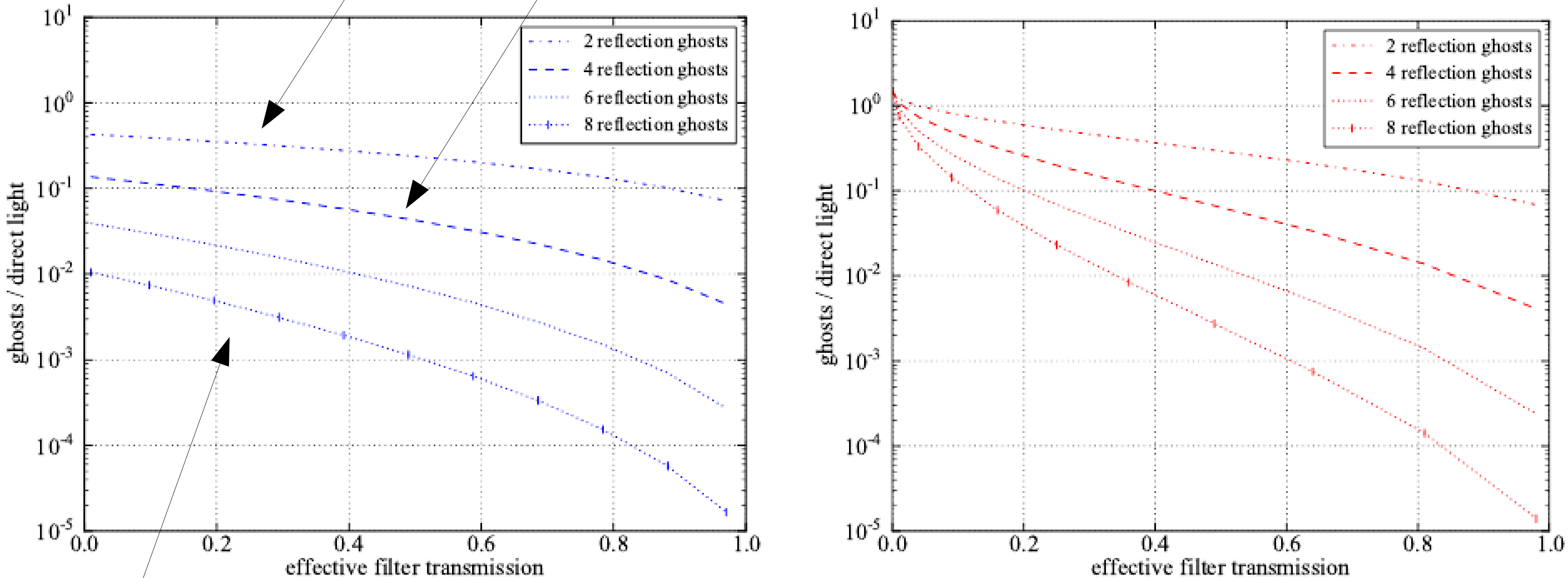
SnDICE LEDs → ~ microWatts / sr / nm → ~ O(1000 e- / s / pixel)

(Regnault et al, submitted to A&A)

Ghosts

105

7201



(a) Direct light & ghost intensities

(b) Ghost intensities (frac. of direct light)

67 221 727

Two different filter models

$$\phi_{\mathrm{ghosts}} = \sum_r N_r \langle R \rangle^r$$

Conclusion

- Steady progress over the last decade
  - ~ 10 years to increase accuracy by a factor ~ 10
- Each step requires
  - New techniques
  - more data
- We are ~ on-par with the precision of the fundamental (HST) flux calibrators
  - Artificial sources under development